MINUTES

OF THE TWENTY-FIRST EXPLOSIVES SAFETY SEMINAR

VOLUME II

HYATT REGENCY HOTEL
HOUSTON, TX
28-30 AUGUST 1984

SPONSORED BY

DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD

ALEXANDRIA, VA

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VOLUME II

Chemical Demilitarization: Disposing of the Most Hazardous Wastes

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This country's aging stockpile of chemical warfare (CW) munitions will eventually require safe and economical disposal. These CW munitions present a unique challenge for demilitarization, since handling of both explosives and toxic material is required. The first full scale projectile disposal facility is presently under design; construction will start on Johnston Island in the summer of 1985. The technology developed for incorporation into the Johnston Atoll Chemical Agent Disposal System (JACADS) maximizes the use of automated equipment, provides the containment necessary to protect the worker and environment, and thermally destroys both the toxic fill and explosives from the CW munitions.

For several decades the United States manufactured CW munitions. Although manufacturing was halted in the late 1960's, large quantities of CW items remain stored in ammunition magazines at eight US Army installations. Periodic inspections performed by ammunition surveillance personnel to verify the condition of these stored items result in munitions being placed into one of several condition codes. Whenever a munition lot is determined to be unserviceable/unrepairable, or becomes obsolete, it is placed into "Condition Code H", to await disposal. At this point it becomes some of this country's most hazardous waste.

Munition types which make up this country's CW stockpile include bombs, rockets, land mines, spray tanks, cartridges, mortars, projectiles, and bulk containers. Disposal of these CW munitions presents a unique challenge, since these items may contain both energetic materials (explosive components) and an extremely toxic fill (chemical agent). (Not all CW munitions are explosively configured; many munitions are stored separately from the explosive components.) The special hazards associated with chemical demilitarization operations require considerable safeguards in order to dispose of this material in a safe and environmentally acceptable manner.

In response to these requirements, the Army has developed methods and procedures on the leading edge of technology for hazardous waste disposal.

This country's CW stockpile is 16-30 years old. The agent contained within the munitions is even older. Although chemical stabilizers were added during agent manufacture, deterioration of the agent fill has occurred during prolonged storage. A special study commissioned by the Department of Defense found that the munition components were not experiencing any metallurgical degradation; however, the study concluded that

the agent was expected to continue to deteriorate. The study predicted 50% ± 10% of the agent would remain in 1990. Another finding was the possibility of catastrophic agent decomposition, once the stabilizer is depleted.[1] These considerations, coupled with this country's efforts to achieve a verifiable ban on chemical weapons, are driving the need for planning for construction of appropriate disposal facilities.

CW munitions presently in storage were not designed to facilitate their eventual disposal; early disposal of CW materiel was primarily accomplished by burial at sea, the last at sea burial being Operation Chase X, in August 1970. Rising worldwide environmental concern led the Department of Army (DA) to commission a study by the National Academy of Sciences (NAS) to investigate disposal alternatives for CW munitions. In response, the NAS concluded "...that all such agents and munitions will require eventual disposal and that dumping at sea should be avoided. Therefore, a systematic study of optimal methods of disposal on appropriate military installations, involving no hazards to the general population and no pollution of the environment, should be undertaken. Appropriately, large disposal facilities should be a required counterpart to existing stocks and planned manufacturing operations. As the first step in this direction, we suggest the construction of facilities for gradual demilitarization and detoxification...".[2] The NAS recommendations for chemical demilitarization were supplemented by DA guidance to insure absolute safety and security rather than cost or time, maximum protection for operating personnel, absolute assurance of total containment of agent, and collection of incontrovertible data to justify personnel safety, security, and community safeguard.

Chemical munitions are maintained in storage in a variety of configurations: some include fuzes, explosive burster charges, and propellant. Lethal chemical agents currently available for military application include mustard and nerve agents. Table 1 illustrates the various munitions which the disposal process must handle and Table 2 provides data on the toxic agents.

Chemical warfare agents are extremely toxic compounds that produce lethal or incapacitating effects on man, depending upon the degree of exposure. (Excluded are riot control agents, chemical herbicides, and smoke and flame materials.)

The term nerve agents refers to two groups of highly toxic chemical compounds that generally are organic esters of substituted phosphoric acid. Nerve agents affect body functions by inhibiting cholinesterase enzymes, permitting accumulation of acetylcholine and subsequent paralysis. Two general categories of nerve agents are currently stockpiled: G agents and V agents. The G agent used in munitions is GB (Sarin); it is a liquid under ordinary atmospheric conditions, with a relatively high vapor pressure. GB is colorless and odorless. It is readily absorbed into the body by inhalation, by ingestion, and through the skin and eyes without producing any irritation prior to onset of symptoms. It is miscible in both polar and nonpolar solvents. It hydrolyzes slowly in water at neutral or slightly acidic pH, and more rapidly under strong alkaline or acidic conditions. The hydrolysis products are significantly less toxic than the agent.

Table 1: US Chemical Warfare Munitions

Designation	Description	Fill	Explosives	Propellant	Fuze
M55	115mm Rocket	10.7 lb GB or 10.2 lb VX	3.2 lb	19.3 lb	Yes
M23	Land Mine	10.5 lb VX	0.8 lb	None	Yes
M2/M2A1	4.2" Mortar	6.0 lb H/HD	0.14 lb	0.6 lb	Yes
M60	105mm Cartridge	3.0 lb H/HD	0.26 lb	2.8 lb	Yes
M360	105mm Cartridge	1.6 lb GB	1.1 lb	2.8 lb	Yes
M110	155mm Projectile	11.7 lb H/HD	0.83 lb	None	No
M104	155mm Projectile	11.7 lb HD	0.83 lb	None	No
M121A1	155mm Projectile	6.5 lb GB or VX	2.45 lb	None	No
M122A1	155mm Projectile	6.5 lb GB	2.45 lb	None	No
M426	8" Projectile	14.5 lb GB or VX	7.0 lb	None	No
MC-1	750 lb Bomb	220 lb GB	None	None	No
MK-94	500 lb Bomb	108 lb GB	None	None	No
TC	Ton Container	1600 lb GB/VX/H	None	None	No
TMU-28	Spray Tank	1356 lb VX	None	None	No

Table 2: CW Agents: Physical & Chemical Properties

	GB	VX	HD
Chemical Name	Isoproply methyl phosphonofluoridate		Bis(2-chloro-ethyl) sulfide
Common Name	Sarin	-	Distilled Mustard
Molecular wt	140.1	267.0	159.1
Liquid Density (25°C)	1.09	1.008	1.27
Freezing point (°C)	-56°	-39°	14°
Vapor pressure at 20°C (mm Hg)	2.2	.0007	.072
Decomposition Temp (°C)	400-560	700-800	149-177
LD_{50} (mg-min/m^3)	100	*	1500
Chemical Formula	$CH_3P(O)(F)OCH(CH_3)_2$	$CH_3P(:O)(OC_2H_5)SC_2H_4N(iso\text{-}C_3H_7)_2$	$(ClCH_2CH)_2S$

*Exposure is primarily via skin penetration. Medium lethal dose is 2.5 mg (equivalent to 0.56 mg intravaneous dose).

The only V agent used in munitions is VX. It is amber in color and odorless. A liquid at normal ambient temperatures, it has an extremely low vapor pressure. Consequently, it is dispersed as an aerosol, and exposure is primarily via skin penetration. The toxicity of VX is 3-10 times that of GB. Exposure of either agent can result in death within minutes.

Blister agents, also called vesicants, are systemic poisons, attacking the eyes and lungs and blistering the skin with either liquid or vapor contact. Most blister agents cause little or no pain on contact. Symptoms of exposure do not usually appear for several hours. Mustard blister agents include Levinstein Mustard (H), and Distilled Mustard (HD); these are the only two mustard agents in munitions.

Pure mustard is a colorless, oily liquid; impurities impart a characteristic garlic odor. It is sufficiently volatile to be effective as a vapor in warm weather.

As was shown in Table 1, each agent can be dispersed by a variety of munitions. Figure 1 illustrates an M360 cartridge. (A projectile, burster, fuze, cartridge casing, propellant and initiator comprise a cartridge). Disposal poses significant challenges:

a. Safe disassembly of the explosives.

b. Disposal of the removed explosive components and propellants.

c. Accessing the agent cavity.

d. Disposal of the toxic agent.

e. Disposal of the munition bodies.

f. Disposal of the process generated wastes.

In addition to these considerations, DA has established criteria for the storage, transportation, and disposal of CW materiel. These criteria address the following areas, and influence selection of disposal alternatives:

a. Restrictions on total quantity of explosives within the process structure.

b. Agent emission limitations.

c. Process effluents standards.

d. Personnel safety requirements.

In September 1979, the Chemical Agent/Munitions Disposal System (CAMDS) at Tooele Army Depot, Utah, became operational. This $67M prototype plant serves as a test facility to evaluate alternate processes for possible incorporation into future large scale production CW demilitarization facilities.

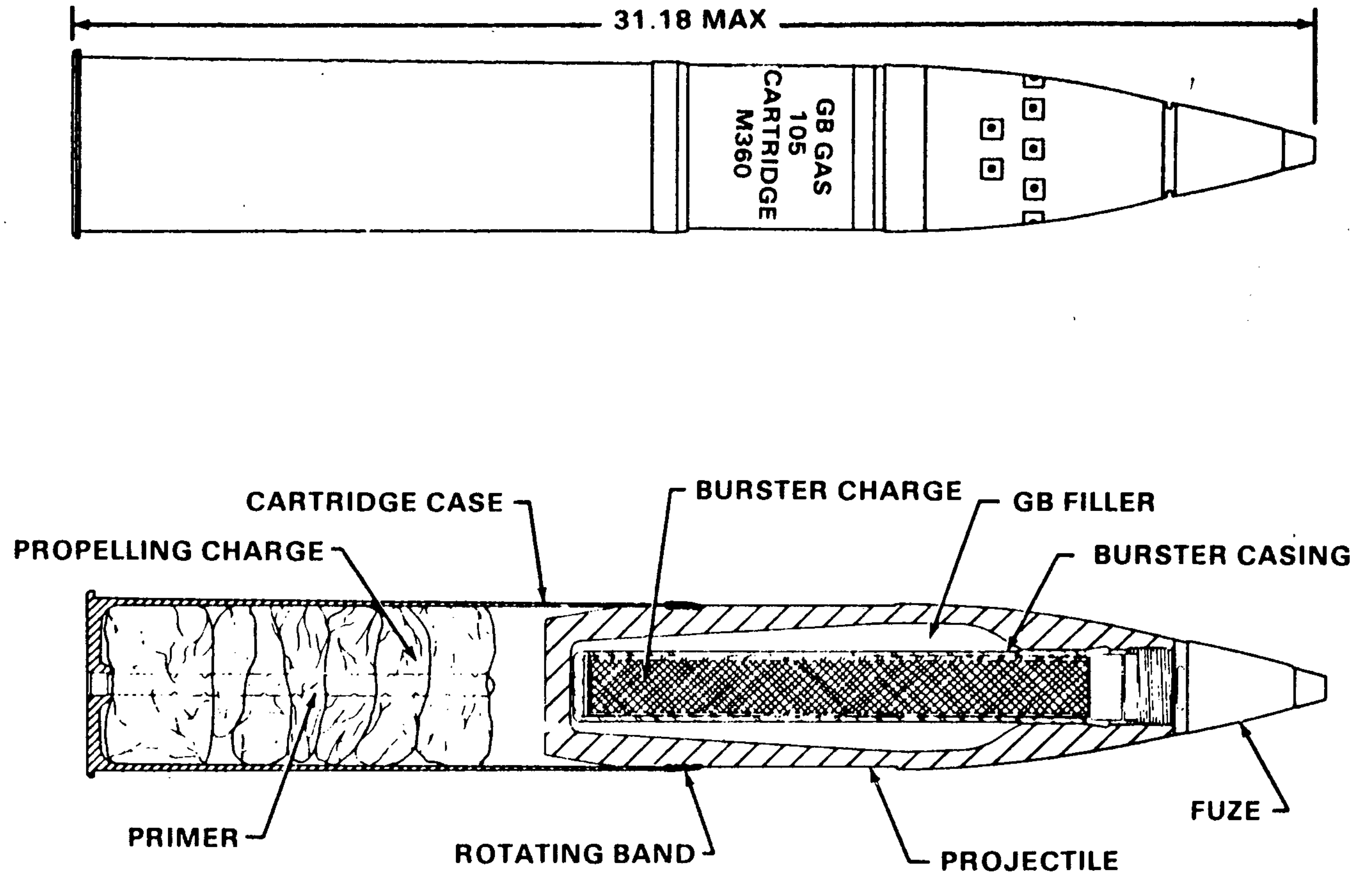

FIGURE 1: CARTRIDGE, 105 MILLIMETER: AGENT GB, M360

The first of these production facilities is currently under design; start of construction is scheduled for the summer of 1985. The facility is to be built on Johnston Island, one of four small land bodies that make up Johnston Atoll (JA), located 717 nautical miles west southwest of Honolulu, Hawaii.

JA is an unincorporated US possession under joint management by the Defense Nuclear Agency (DNA) and the Department of Interior (DOI). Johnston Island, the largest body in the Atoll, is approximately 2 miles long and 1/2 mile wide, and covers 630 acres. The Atoll is both a wildlife refuge monitored by the Fish and Wildlife Service, and a contingency site maintained by DNA for resumption of above ground nuclear testing.

The CW stocks stored at JA came originally from Okinawa in 1971 as a result of their prohibition from being returned to the United States by Public Law 91-672.

When DA gave direction in March 1981 to initiate planning for disposal of the Code H munitions on JA, environmental considerations were given priority. A public scoping meeting was held in Honolulu, HI in June 1983 and a final EIS published in November 1983. Of the viable alternatives, construction of a state-of-the-art disposal facility on JA was determined to offer the best solution. The technology selected is that being demonstrated by the CAMDS prototype facility.

The key elements of this technology are illustrated in Figure 2 and provide the basis for design of the JACADS process and facility. The site layout is shown in Figure 3.

The overriding facility criteria is agent containment. By maintaining negative pressures within the facility, agent containment is provided for all processing steps. The resulting ventilation air is scrubbed by redundant charcoal filters as illustrated in Figure 4. These filters are 99.99999% efficient in removal of agent prior to discharge of the ventilation air to the atmosphere. Containment of both the overpressure and fragments resulting from an accidental detonation is provided for those process steps involving explosively configured munitions. This total containment is accomplished by use of a reinforced concrete structure contained within the facility. Blast valves and containment dampers isolate this structure from the rest of the facility in the event of an accidental detonation.

The specific process steps and equipment required for demilitarization are a function of the munition type. Generically, all munition types fall into one of three categories:

a. Rockets and Mines. These thin-walled munitions are processed without removal of their explosive components.

b. Projectiles and Mortars. Removal of explosives from these heavy-walled munitions is the first processing step.

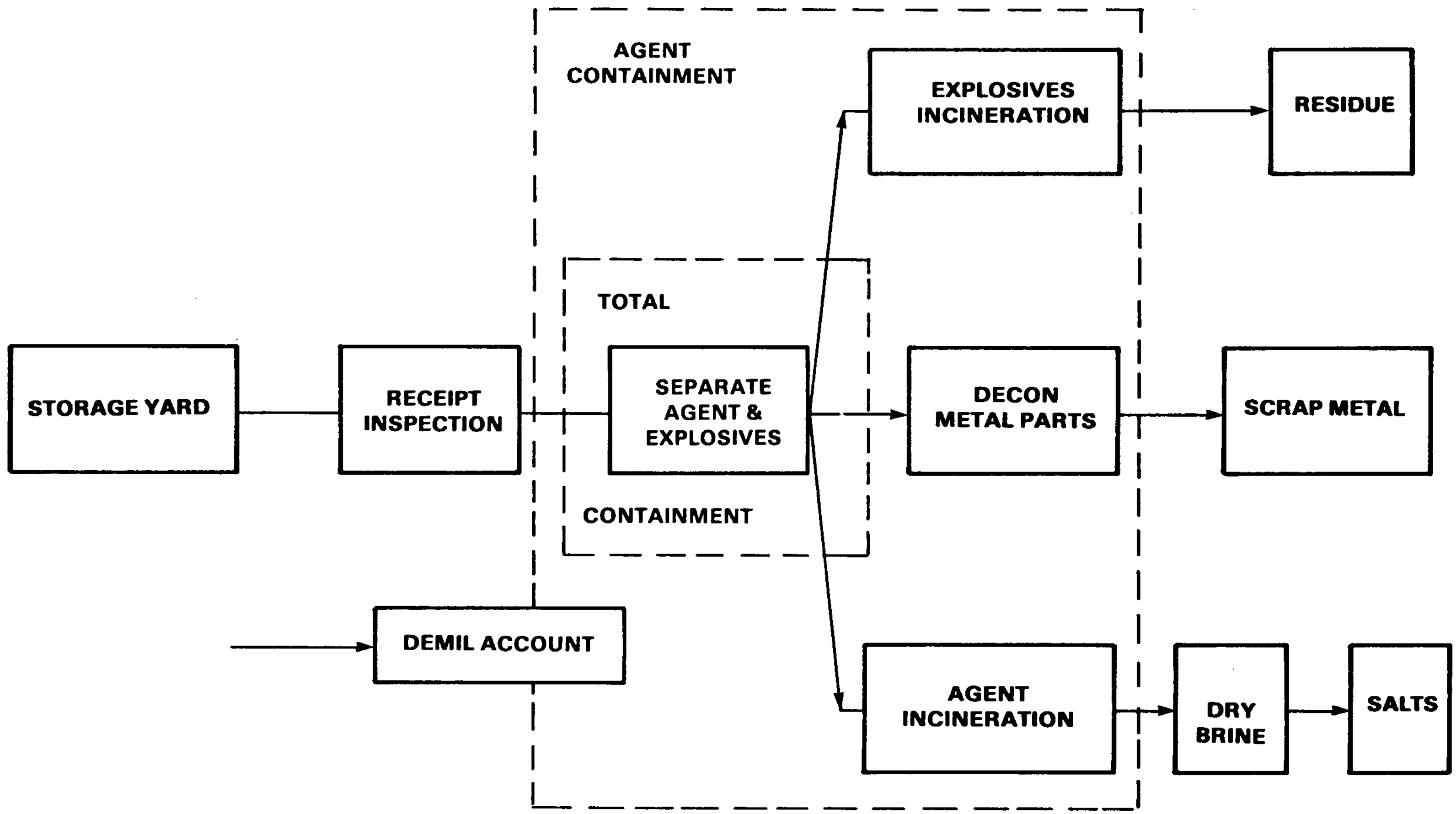

FIGURE 2: CHEMICAL MUNITION DEMILITARIZATION SCHEMATIC

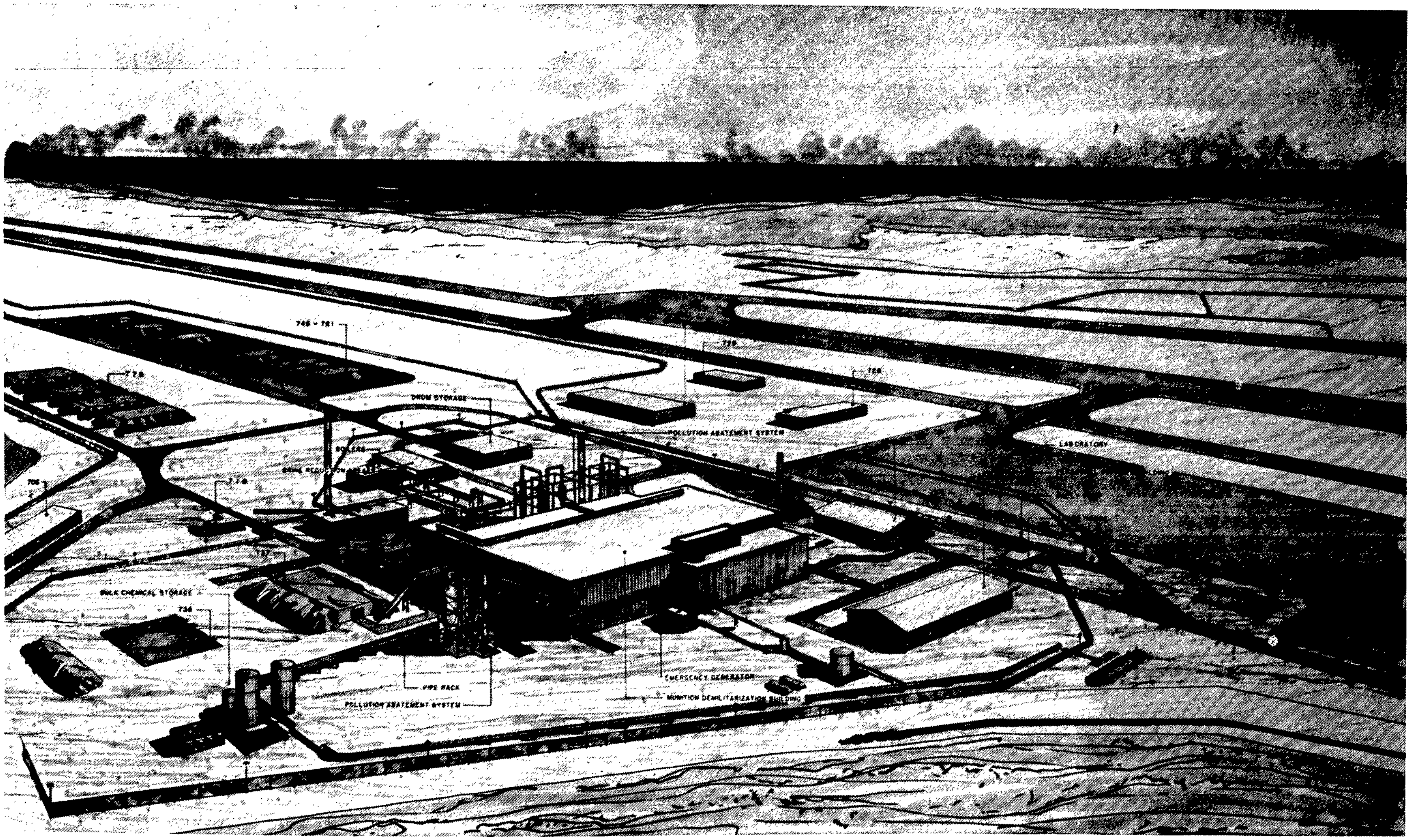

Figure 3: Perspective View of Site – Johnston Atoll
Chemical Agent Disposal System

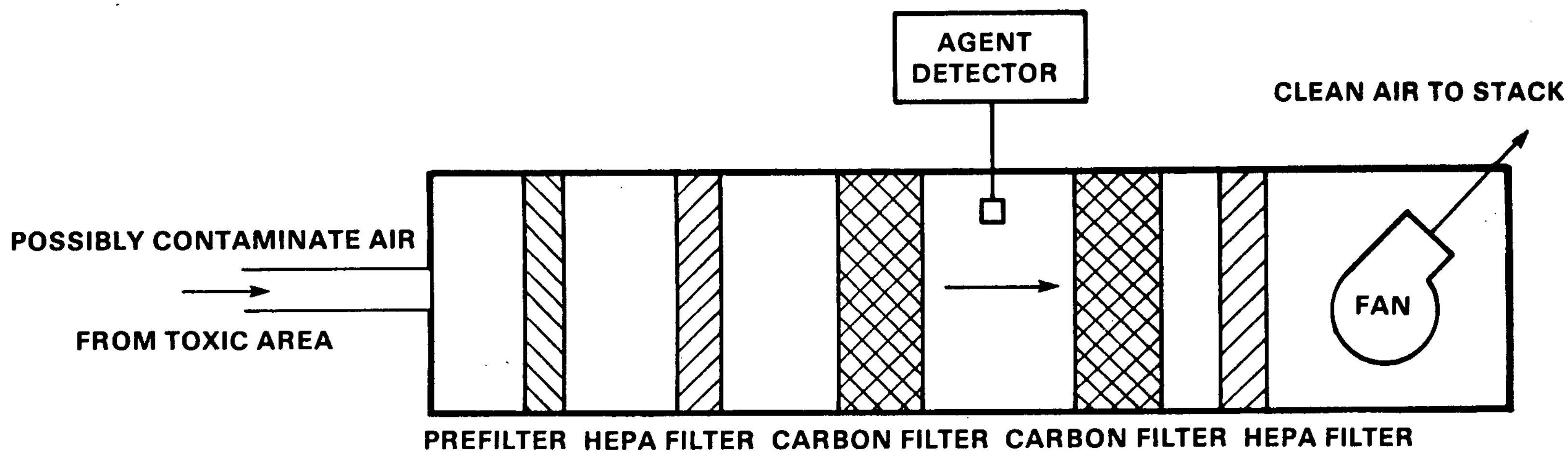

FIGURE 4: TYPICAL FILTER HOUSING LAYOUT

c. Bulk Items. This category includes bombs, spray tanks, and ton containers; they do not contain explosives in their storage configurations.

For all three munition categories, the demilitarization process involves two distinct operations: preparation for thermal treatment, followed by thermal processing; agent destruction is accomplished by incineration.

The JACADS facility has been designed with the capability to process all three munition categories. The primary process facility comprises 67,000 sq ft on two levels. The second floor houses the equipment required for preparation of the munition for thermal processing while the process's four furnaces are located on the ground level facilitating gravity feeding of munition components into the furnaces. The four process furnaces: the liquid incinerator, deactivation furnace, metal parts furnace, and dunnage incinerator, are the heart of the demilitarization operation. The following paragraphs discuss the role of each of these furnaces in the disposal operations.

Chemical agent, drained as a liquid from all munitions and pumped to intermediate holding tanks, is incinerated by the liquid incinerator.

The liquid incinerator has been designed with the capabilities shown in Table 3.

Table 3: Incineration Rates

	lbs/hr
GB	1050
VX	700
Mustard	1330
Decontamination Solutions	2000

Agent pumped from the intermediate holding tanks is atomized by a spray nozzle into the primary chamber of the two chamber furnace. The resultant combustion products are further incinerated in the secondary fume burner. The following incinerator criteria has been established for the liquid incinerator:[3].

Table 4: Agent Incinerator Criteria

	Primary Chamber	Fume Burner
Burner Zone Temperature	2500-3500°F	2500-3500°F
Secondary Zone Temperature (avg)	1800-2200°F	2000°F
Residence Time	2.0 sec	.5 sec

In the design of an agent incinerator, the overriding criteria is destruction efficiency. Table 5 illustrates the degree of destruction required for each agent.

Table 5: Agent Incinerator Destruction Requirements (200% Excess Air)

Agent	Discharge Std (mg/m^3)	Required Destruction Efficiency (%)
GB	0.0003	99.999999
VX	0.00003	99.9999999
H	0.03	99.99995

Disposal of the munitions' explosive and propellant components is accomplished by incineration. Energetic material is fed into a deactivation furnace system. Bursters and rocket propellants are preprocessed through a mechanical shear. This shear reduces the size of the material and exposes additional surface area to facilitate controlled combustion rather than detonation. Fuzes, booster pellets, and supplementary charges are fed to the furnace intact.

The deactivation furnace consists of a steel rotary retort kiln, operated at 1200°F, and a heated discharge conveyor, operated at 1000°F. Residence time of the explosives inside the retort is approximately 12 minutes - sufficient to allow complete burning of all energetic material. Upon exiting the retort, the non-combustible components travel on the heated discharge conveyor for an additional 15 minutes to insure complete thermal decontamination of any residual agent. The deactivation furnace system is capable of processing approximately 500 lbs/hr of explosives.

The exhaust of the deactivation furnace exits through a blast attenuation duct prior to entry into a secondary fume burner. The secondary fume burner has been designed to the same criteria as the liquid incinerator afterburner. The deactivation furnace room has been designed to provide containment of all fragments, overpressure and agent in the event of a detonation during the incineration process.

In addition to the agent and explosives, the munition metal parts constitutes a third category of hazardous waste. Metal which has been in contact with liquid agent has been shown to release agent vapors when subjected to elevated temperatures, even after the metal has been chemically decontaminated. For this reason, all metal parts are thermally decontaminated to a criteria of 1000°F for 15 minutes prior to discharge from the process areas. Since rockets and land mines are processed without removal of their explosives, metal parts from these munitions are decontaminated in the deactivation furnace system concurrent with incineration of the energetic material. Metal parts from projectiles, mortars, and bulk items are processed through a separate metal parts furnace system for thermal decontamination. This modified roller hearth furnace is

designed to process metal parts through the furnace on reusable 3' x 10' trays with a residence time of approximately 60 minutes. The throughput rates of this furnace are a function of the munition types, as shown in Table 6.

Table 6: Munition Peak Processing Rates

Munition Type	No./Hour	Lbs/Hour (Metal)
105	181	5800
4.2	178	3200
155	90	8100
8"	47	8700
Bombs	2.4	1200
TCs	1.66	2600
Rockets	60	-
Mines	72	-

In addition to the decontamination of metal parts, this furnace has been designed to incinerate a residual agent "heel" of 5% by weight of the agent fill of each munition. Exhaust gases from the decontamination chamber of the metal parts furnace are incinerated in a secondary fume burner.

The fourth furnace system within the demilitarization facility is the dunnage incinerator. This incinerator is designed to burn all process dunnage including agent contaminated wood, wooden pallets impregnated with PCP preservatives, contaminated protective clothing, and other packaging materials. The combustion chamber is a refractory lined incinerator operated at approximately 2000°F. A ram feed processes materials into the furnace, simultaneously discharging ash from the opposite end. A secondary fume burner assures complete incineration of all hydrocarbons. The incinerator has a throughput rate of approximately 1000 lbs/hour of combustible dunnage. Although all furnaces are fired by No. 2 fuel oil, a substantial portion of the heat input is provided by the combustion products. Table 7 shows BTU's/hr from combustion of the waste inputs.

Table 7: Incineration Combustion Rates

		BTU's/hour
Liquid Incinerator	GB	9,580,000
	VX	9,331,000
	H	9,520,000
Deactivation Furnace	Explosives	993,000
	Propellant	3,185,000
Dunnage Incinerator	Wood	8,000,000

Each furnace system has an independent pollution abatement system designed to scrub the products of combustion. Primary products of combustion are shown below.

GB:	CO_2, H_2O, P_2O_5, HF
VX:	NOx, P_2O_5, SO_2, CO_2, H_2O
Mustard:	CO_2, SO_2, HCl, H_2O

In addition, impurities in the agents result in trace quantities of heavy metals in the furnace exhaust.

Figure 5 illustrates the basic pollution abatement system; similar systems are utilized for three of the four process furnaces. The incinerators have been designed for compliance with applicable RCRA (HCl and particulate emissions) and Clean Air Act requirements. The exhaust of the secondary fume burner is drawn through the pollution abatement system by an induced draft fan. The quench reduces the afterburner exhaust to approximately 200°F and results in adiabitic saturation of the effluent stream. Eighteen percent caustic solution is used as a quench media to assure neutralization of any acid gases condensed in the quench. The high energy venturi is a variable throat venturi with an approximate 40" WG pressure drop designed to provide 99% efficiency in removal of particulate larger than 0.5 microns. The counter-flow caustic scrubber uses stainless steel pall rings to scrub remaining acid gases. Mist eliminators are used primarily for removal of P_2O_5, but also to entrain particulate not removed by the venturi. The mist eliminators have been designed with a counterflow acid wash to prevent plugging by small particulate metal oxides.

Liquid effluent from the pollution abatement system is discarded when the specific gravity reaches 1.08 - 1.20, depending upon the agent being processed. Excess water is evaporated from this effluent yielding a waste salt suitable for landfill.

While the furnace system is the heart of the demilitarization system, the control room is the brains. With the exception of the munition input and residue removal, the demilitarization operation is totally automated and controlled from the control room.

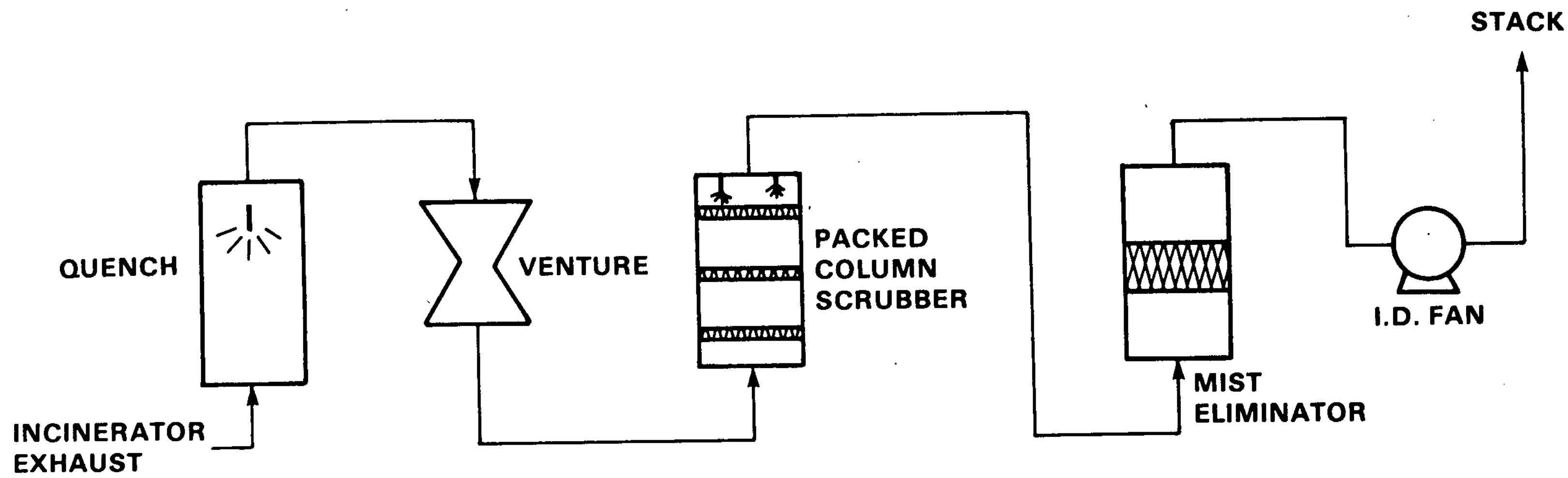

FIGURE 5: INCINERATOR POLLUTION ABATEMENT FLOW DIAGRAM

Munition processing is accomplished by machines designed and built for specific chemical demilitarization operations. This equipment includes: the Rocket Shear Machine for shearing rockets and explosives, the Projectile/Mortar Disassembly Machine for removing explosive components by reversing the assembly process, the Multipurpose Demilitarization Machine for draining agent from projectiles and mortars, and the Bulk Drain Station for punching and draining bombs, ton containers, and spray tanks. Robots are used for munition handling within the process area. Process information is continually fed to the control room for computer analysis. The control room operators are provided with closed circuit television to facilitate monitoring of the process flow. Additionally, observation corridors surround the process area, allowing for direct viewing of these areas, if needed.

Although the demilitarization equipment has been designed to preclude the requirement for operators in the process area, personnel entry is required to affect maintenance or repairs. Maintenance personnel entering agent process areas are protected from exposure to chemical agents by the Demilitarization Protective Ensemble shown in Figure 6. This air supplied protective suit was developed specifically for chemical demilitarization operations. In addition to the air supply umbillical, the suit is provided with a backup self-contained respirator for emergency egress in the event of a loss of supply air.

In use, the worker is heat-sealed into the disposable chlorinated polyethelene suit and a helium leak test is performed to insure a complete seal. Personnel entry into toxic areas requires at least two individuals and visual contact must be maintained betwen the workers in any one area. Each worker in the protective ensemble can communicate with the control room and other personnel via an RF communications system.

Normal clothing for workers in the noncontaminated areas of the facility is cotton coveralls. Each worker carries a protective gas mask which can be donned in the event of an agent alarm or process upset. The differential pressures within the facility have been designed to prevent migration of agent into noncontaminated work areas. These differential room pressures are constantly monitored by the control room.

All work areas, the control room, and furnace and filter exhausts are continually monitored for agent during operations. The primary agent monitor used is the Automated Continuous Agent Monitoring System (ACAMS) developed for demilitarization operations. The ACAMS is an on-line automated gas chromatograph capable of specific identification of the chemical agents at concentrations less than the allowable work area limits established by the DA Surgeon General as listed in Table 8.

Table 8: Allowable Work Area Concentrations (Time Weighted Average)

GB	.0001 mg/m^3
VX	.00001 mg/m^3
H	.003 mg/m^3

Figure 7: Demilitarization Protective Ensemble

As shown in Figure 7, the ACAMS includes a preconcentration tube, a GC column, and a flame photometric detector. In operation, sample air is drawn through the preconcentrator tube for a predetermined period. At the end of this period the sampling is interrupted and the preconcentrator tube is heated. A counter-flow carrier gas desorbs any agent accumulated in the preconcentrator. The desorbed sample is drawn through a Gas Chromatograph column designed to separate the sample constituants prior to introduction into the flame photometeric detector. The ACAMS is controlled by an internal microprocessor and provides both an analog and digital output. The output is displayed locally as well as transmitted to the control room.

Data from the air monitors provide a permanent record of plant emissions as well as a record of the potential for exposure of personnel to agents. Additionally, routine medical examination of plant personnel is used to monitor indications of agent exposure.

Subsequent to the termination of ocean disposal in 1970, the Army has disposed of over 15,000,000 pounds of CW agents, The procedures and equipment developed and being implemented by the Army have demonstrated that disposal of even the most hazardous waste can be accomplished safety with minimal impact to the environment.

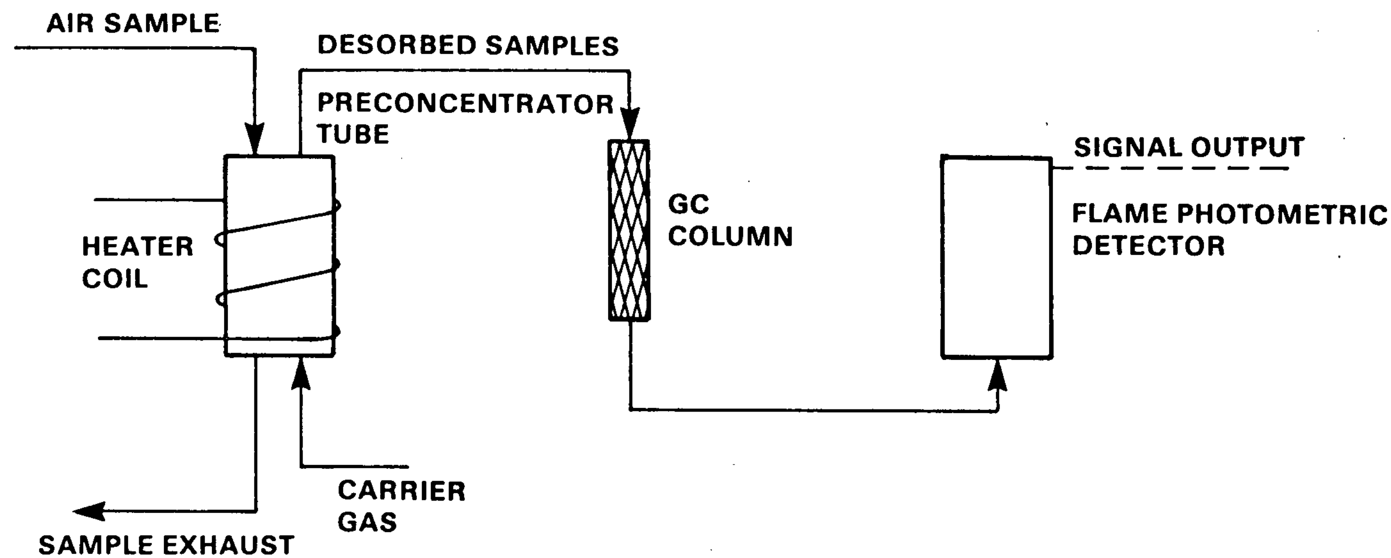

FIGURE 7: SCHEMATIC OF AUTOMATED CONTINUOUS AGENT MONITORING SYSTEM (ACAMS)

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DESENSITIZATION AND CONVERSION
OF
AMMONIUM PICRATE (EXPLOSIVE D) TO FUEL

REPORT PRESENTED AT
DOD 21ST EXPLOSIVES SAFETY SEMINAR
1984

BY

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SUMMARY

Background

Recovery of Explosive D incidental to demilitarization of munitions by a hot water washout technique planned for use at the Western Area Demilitarization Facility (WADF), results in plating of process piping and equipment with explosive crystals as the Explosive D slurry cools.

The solidification and plating of process equipment by Explosive D crystals would create serious operational problems and present a hazardous condition during dissassembly and repair of equipment. The Ammunition Equipment Directorate (AED) of Tooele Army Depot, was tasked by the U.S. Army Armament, Munitions and Chemical Command (AMCCOM) to develop a process to prevent Explosive D from solidifying and plating onto the surface of process equipment and piping.

In addition, the WADF processes would possibly involve the mixing of explosive D with traces of other explosives from previous operations, resulting in a number of associated hazards:

1. Explosive D, and its parent compound, picric acid, corrode metals, forming picrate salts of those metals. Such salts are much more sensitive to detonation than the original explosives.

2. Some explosives are compounded or complexed with Explosive D, producing more sensitive materials.

3. Chemical reactions of Explosive D with other explosives may generate excess heat, thereby causing a fire hazard.

Research Approach

Reports of past work in the industrial, academic, and military communities, were searched by AED. This resulted in the following selection of methods for further considerations.

1. Suspension in a gelling medium
2. Solid dilution
3. Solvation
4. Chemical conversion
5. Catalytic conversion
6. Electrolytic reduction

Laboratory work and analyses indicated that the methods of solvation and chemical conversion of Explosive D/water slurry were the most feasible avenues to follow.

Scope and Parameters

With the direction of the effort determined, the project scope was expanded and redefined by AMCCOM to include the following parameters for the process and the resulting product:

1. The product must be proven stable for a minimum of three months, with a one-year stability being desirable.

2. The product must be combustible, with no hazardous products of combustion being formed that would be harmful to people or the environment, in compliance with EPA regulations.

3. The product and the residue from evaporation of the volatiles in the product should be no more sensitive to detonation than Yellow D itself.

4. The product and its residue must be compatible with all materials contacted during processing, transporting, pumping, and burning.

5. The product must not plate equipment with solid or form any precipitate during processing or storing, at any natural temperature that may be encountered.

6. Complete parameters should be provided for the process, including chemical conversion, handling, transportation, storing, and burning at WADF.

7. A standing operating procedure must be provided.

8. Any undesirable impact on WADF facilities must be minimized.

Results

The chemical conversion process, consisting of a weak base reaction using n-butylamine and alcohol, appeared to provide the best results within the parameters defined. A pilot plant with a maximum batch capacity of 65 lbs of Explosive D was fabricated to test the process and evaluate the product within the parameters.

The best process tested was a reaction of Explosive D/water slurry with n-butylamine for one to three hours at 70°C, producing a brown oily liquid. Addition of methanol reduced the viscosity, increasing the pumpability of the liquid.

The resulting product has the following properties, as shown by various tests and analyses.

1. The liquid product is stable in storage (no precipitation or plating) as demonstrated by observation during 3.5 months of storage.

2. The liquid product does not detonate in zero gap tests.

3. The solid residue after evaporation of volatiles from 3-week old product is approximately 30% less sensitive than TNT or Explosive D.

4. The liquid product can be burned in a furnace as a fuel while producing effluents that are in compliance with EPA regulations.

5. The liquid product, and solid residue after evaporation of volatiles, are compatible with materials recommended for use in processing, handling, and storage equipment over a temperature range of -20°C to 70°C.

6. The liquid product remains liquid and does not plate solids onto equipment surfaces over a temperature range of -20°C to 70°C.

Independent Evaluations

Picatinny Arsenal conducted independent evaluations of the process, and of the sensitivity of the product. Toxicology tests of reaction materials and the resulting liquid conversion product were conducted by the U.S. Army Environmental Hygiene Agency. The liquid product was insensitive to detonation and showed no more toxicity than the starting components. Effluent gases from burning the liquid product were analyzed by Brigham Young University, showing that NO_x was near zero and CO was about 1%.

Application

Engineering parameters have been developed by AED for application of the process to the hot water Explosive D washout system at WADF. The proposed process equipment can be incorporated at WADF with minimal impact on existing facilities and equipment.

Conclusions

This project has been completed with all specified parameters having been met. The chemical conversion process for Explosive D/water slurry, developed by AED, produces a stable, insensitive, liquid product that eliminates the plating problems of Explosive D washout, and burns as a fuel in compliance with EPA regulations.

Engineering parameters have been developed for the designing of process equipment that can be installed at WADF with minimal impact on existing facilities.

Recommendations

It is recommended, if no other ecologically viable methods exit for the disposal of Explosive D, that this chemical conversion process be applied at WADF or other demil location for the disposal of Explosive D/water slurry.

In addition, based on the Explosive D project just completed at AED, it is suggested that the following aspects of Explosive D and related explosives be investigated.

1. The dewatering system must be perfected in WADF equipment before this final process is applied.

2. A fuel injection system should be developed for the introduction of the Explosive D conversion product into existing furnaces at WADF.

3. Consideration should be given to the recovery of the ammonia gas evolved during the chemical conversion process for use in producing a useful by-product such as fertilizer, or for use in reducing pollutants in the incineration.

4. Further analytical work should be conducted to determine the potential hazards of metallic impurities found in washed-out Explosive D, to identify the degradation products of the converted Explosive D as it ages, and to elucidate the mechanisms of degradation.

5. The possible conversion of other explosives to fuels should be investigated on the basis of principles developed in this project.

6. AED could provide consultation on the design of the process equipment, if this process is used at WADF.

7. Additional in-vitro and in-vivo tests should be conducted to observe the long-range toxicity and mutagenic properties of ammonium picrate and the Explosive D conversion product.

INTRODUCTION

Background

Waste explosives (TNT, RDX, Comp B, Explosive D, etc.) are continually generated by the United States Military during the manufacture of explosives, the loading and assembling of munitions, and during the demilitarization of unserviceable or obsolete bombs, projectiles, and other munitions.

The main methods currently employed by the United States Military for the disposal of waste explosives are: (1) open air detonation, (2) open air burning, (3) washout, and (4) incineration in specially designed furnaces.

In the past, such demilitarization procedures were considered as cost effective and timely methods for the disposal of waste explosives. The once largely manual demilitarization operation of the past was considered attractive due to inexpensive labor and operating procedures. This is no longer true with the current high labor cost, and expenses associated with the safeguarding of operators from undue exposure to explosives. Futhermore, little consideration was given to potential environmental effects. Currently, both the government and the public have come to realize that such disposal methods contribute, however minutely, to the overall environmental pollution problem.

In response to the environmental protection laws which have been enacted, e.g., the Clean Air Act, the Resource Conservation and Recovery Act, and Toxic Substances Control Act, the U.S. Navy formulated and proceeded to construct a waste explosives disposal facility. This disposal facility, the Western Area Demilitarization Facility (WADF) now located within the Hawthorne Army Ammunition Plant, Hawthorne, Nevada, is designed to process small caliber munitions as well as large tonnage bombs, projectiles, and mines loaded with high explosives such as TNT, RDX, Comp B, A-3, and Explosive D.

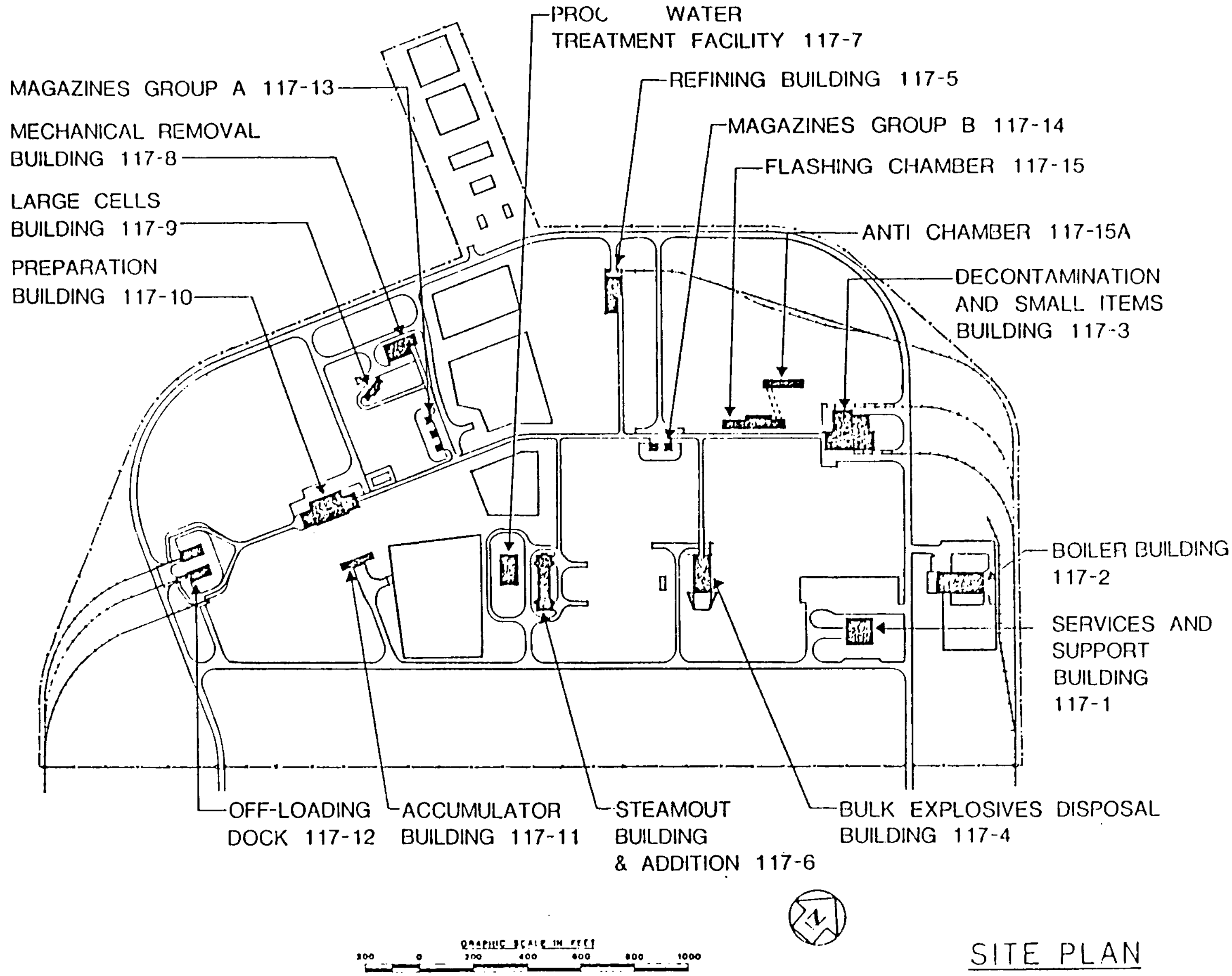
Demilitarization and Disposal of Explosive D

A survey of the JCAP inventory showed that a large quantity of Explosive D loaded munitions has been marked for demilitarization and disposal. Accordingly, WADF plans to dispose of over 147,000 pounds of Explosive D munitions.

The demilitarization and disposal operations for Explosive D (Yellow D or ammonium picrate) are conducted at WADF in five major process buildings and facilities. Hereafter in this report the terms Explosive D, Yellow D and ammonium picrate are used interchangeably.

The munitions are received and unloaded at the Off-Loading Dock Building, and then transported to the Preparation Building where they are defuzed and disassembled. The munitions are then transported to the South Tower of the Washout Building where the explosive is removed from the munitions using the high pressure hot water washout technique. Refer to Figures 1 for the general layout of WADF.

The Yellow D/water mixture removed from the munitions is allowed to flow by gravity from the washout chamber or the washout table into a heated storage tank where the mixture is mechanically stirred. From the storage tank the explosive slurry is transported to the Bulk Explosive Preparation Building by driverless transporter.



Western Area Demilitarization Facility

Figure 1

When other explosive/water mixtures such as TNT/water or TNT-RDX/water (produced by the steamout process in the North Tower) are delivered to the Bulk Explosive Preparation Building, further processes are required to maintain appropriate explosive/water ratio and particle size. The Yellow D/water mixture, however, when delivered to the building from the transporters, by-passes these additional processes and is introduced directly into the slurry tank, from which it is pumped to the feed tank.

The slurry is pumped to the Incineration Facility where it is burned in two rotary kilns, each of which require approximately 263 gallons of No. 2 fuel oil for each 1,000 pounds of Yellow D burned.

All aspects of the demilitarization and disposal operations, from the unloading to the burning, are controlled remotely by operators in the central building where they are protected from the possibility of detonations.

Definition of Problems

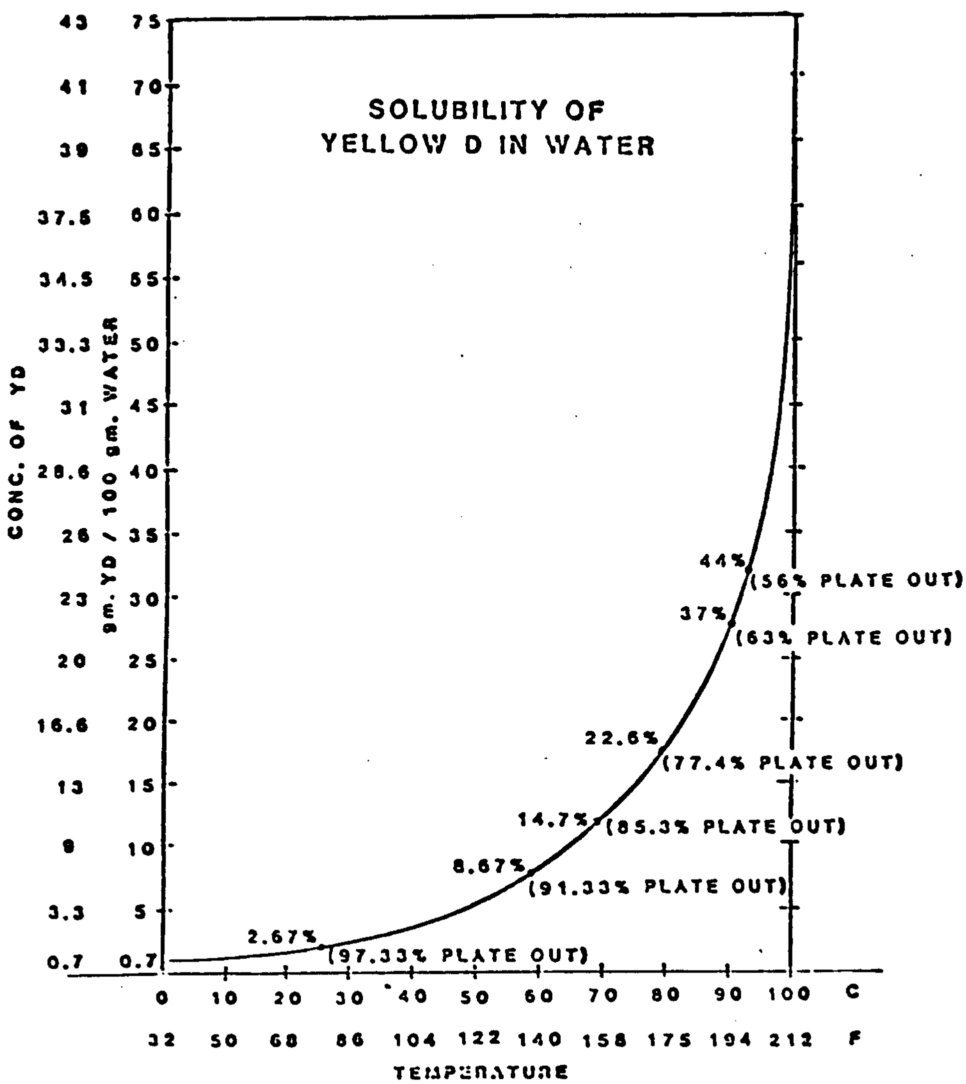
The Yellow D solution produced in the washout operation coats the process equipment (valves, pumps, drainage system, etc.) with a layer of explosive solid (see Figure 2). The fouled process equipment must then be dismantled carefully and cleaned or disposed of by incineration in a furnace which is specially constructed to handle the explosive-contaminated equipment.

Process failure is explained by the chemistry of the Yellow D/water solution. When Yellow D is initially washed out of the munitions, it is partly an aqueous solution and partly a suspension of solid Yellow D. However, during the subsequent operations of transporting, mixing, and pumping, the temperature of the solution is lowered through conductive heat losses, which drives the dissolved solid out of solution and plates Yellow D on the equipment. Figure 3 shows this relationship of Yellow D solubility with temperature.

COAT OF YELLOW D INSIDE SECTION OF PIPE

ILLUSTRATED EXAMPLE OF PLATING PROBLEM IN PIPE

FIGURE 2



EXPLOSIVE D SOLUBILITY IN WATER AS
A FUNCTION OF TEMPERATURE

FIGURE 3

Furthermore, a number of associated explosion hazards exist from potential chemical reactions of picrates with other explosives or with contact materials, as described by the following examples.

1. A small amount of metal and magnetic material, in the form of chips and powder is present in Yellow D recovered by the wash-out process. Yellow D and its parent molecule, picric acid corrode many metals, forming picrate salts of those metals. Some such salts are very sensitive to detonation and are strong enough explosives to detonate wet TNT or picric acid. Some metals are attacked more readily by picric acid and others more readily by Yellow D. Metal oxides and salts react with Yellow D more quickly than metals do. Iron, nickel and chromium are major components of stainless steel. Sodium, potassium, calcium, magnesium and barium are present in concrete. Copper, zinc, tin and lead are present in plumbing fixtures and electrical parts. Industrial literature recommends the use of copper, tin-plated steel, or stainless steel equipment, because of their relative inertness to attack by picric acid.[1,2,3]

2. If equipment is used to handle several kinds of explosives as planned at WADF, an additional hazard exists. Some explosives are compounded or complexed with metals, metal oxides, or with metal salts. Traces of such residues present in hard to clean parts and in microfissures of the metal-crystal structure of process equipment can

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[1]Kaye "Encyclopedia of Explosives and Related Items," _8_, _9_.
[2]Urbanski, "Chemistry and Technology of Explosives."
[3]Note the extreme sensitivity of the first four items in Table 1.

then become exposed to Yellow D in subsequent operations. The products of such compounding and complexing would be more sensitive than Yellow D itself. A sensivity list of some representative picrates is given in Table 1.

3. Yellow D mixed with some other explosives may not only become more sensitive as mentioned above, but may undergo chemical reactions which would generate heat, thereby causing a fire hazard.

4. Explosive D is normally about as sensitive to detonation as TNT. As the ammonium salt of picric acid, Explosive D has a more sensitive red form, which exists in crystals which have more than a 1:1 molar ratio of ammonia to picrate.

TABLE 1

Picrate Formation And Sensitivity[4,5,6]

Lead picrate	Highly sensitive - about like mercury fulminate!
Iron(III) picrate	Highly sensitive - about like PETN!
Cobalt picrate	Highly sensitive!
Nickel picrate	Highly sensitive - between MF & Tetryl!
Chromium picrate	More sensitive than TNT (multiple hydrates less than TNT).
Barium picrate	Slightly more sensitive than TNT.
Copper picrate	About as sensitive as TNT, more or less depending on type of test, forms with difficulty
Manganese picrate	Slightly more sensitive than TNT.
Zinc picrate	Slightly more sensitive than TNT.
Cadmium picrate	Slightly more sensitive than TNT.
Calcium picrate	Slightly more sensitive than TNT.
Magnesium picrate	Sensitivity not given.
Iron(II) picrate	About as sensitive as TNT.
Picric acid	About as sensitive as TNT, more or less depending on type of test.
Sodium picrate	Slightly less sensitive than TNT.
Potassium picrate	Slightly less sensitive than TNT.
Ammonium picrate	Slightly less sensitive than TNT.
Aluminum picrate	Slightly less sensitive than TNT, forms with difficulty.
Tin picrate	Not listed. Tin is inert to picric acid.
Stainless steel	Inert to picric acid. Microscopic crystalline structure reactivity to picric acid not given.

[4,5,6]See reference 1, 2, 3, and other work of Kaye and Urbanski.

Objective and Limitations

In September 1980, the Ammunition Equipment Directorate, Tooele Army Depot, was tasked by the US Army Armament Materiel Readiness Command (ARRCOM) to develop a process which would eliminate the solidification and plating of Yellow D on process equipment.

As work progressed, it became apparent that the solvation/conversion processs of Explosive D/water slurry was the most promising solution to the problem of solidification and plating of Yellow D. Therefore, the objective of the project was redefined and expanded to include additional engineering parameters listed below.

1. The Yellow D solvation/conversion product, hereafter refered to as the conversion product, must be proven stable for a period of at least three months, with a one year stability being desirable.

2. The conversion product must be combustible, and its residue from evaporation of volatiles should be no more sensitive than Yellow D itself.

3. Characteristics of the conversion product, and the process equipment design should assure that emissions from burning comply with EPA regulations.

4. The conversion product and its residue after the evaporation of volatiles should be compatible with all the other materials contacted during the processing, transporting, pumping, and handling operations, regardless of the concentrations experienced in the solvation and conversion process.

5. The conversion product must be stable without solidification at storage temperatures down to -15°C (-5°F). The temperature was chosen to be much lower than the observed low of 8°F during 1981-2 at Hawthorne, Nev.

6. Under ambient and process temperatures, the conversion product must neither plate-out on the equipment nor form any precipitate during any part of the processing or handling operations.

7. Process parameters for the Engineering Effort (pilot plant II) should be provided.

8. A complete Standing Operating Procedure should be provided.

9. The process developed as a result of this project should not be so radical in nature that implementation would interrupt or alter the existing facilities, or depart drastically from the basic demil/disposal concept that has already been adopted at WADF. Rather, the project should proceed with a plan that will solve the problems by utilizing the existing operational flow and process equipment.

Scope Of Project

The scope of this project expanded as the work progressed to include the following:

1. A literature search should be carried out to review past work related to the solvation and conversion reactions of polynitro aromatic compounds such as Yellow D, picric acid, and TNT.

2. Laboratory work should be conducted to verify the results reported in research literature and to formulate new approaches concering the solidification problem of Yellow D.

3. A pilot plant study should be made to gather further engineering data, and to manufacture sufficent products for sensitivity and toxicity tests.

4. Combustion tests should be conducted to determine the combustibilty of the product in existing demilitarization furnace and in other systems such as steam generating boilers or gas turbine engines.

TECHNICAL DISCUSSION

Introduction

Based on the objectives outlined within the scope of the original tasking, a general literature survey was initiated to review what research and development had already been published. This was followed by the formulation of possible experimental approaches. The laboratory work was conducted at the chemical testing facilities at the Ammunition Equipment Directorate, Tooele Army Depot, Tooele, Utah and at Brigham Young University, Provo, Utah.

Results of the experimental work indicated that a solvation/conversion method was the most promising approach, in that it gave a final product which met all the requirements outlined in the project tasking. This conclusion led to the development of a two-phase pilot plant engineering study. Both pilot plants, phase I and phase II were designed and fabricated by the Ammunition Equipment Directorate (AED) and installed at the chemical testing facility. The first pilot plant was designed to process 25 pounds of Yellow D, and the second was a scaled-up and more sophisticated version with a 65-pound Yellow D processing capacity.

Test reactions were conducted to gather data from which engineering parameters could be developed for application of this project at WADF. Hazard and safety studies were conducted by appropriate agencies to ensure the safe handling of the reaction products. To complete the required task, a burning test of the products was conducted in a simple furnace designed and fabricated by AED to determine the feasibility of using the product as fuel. Preliminary effluent gases did not contain harmful pollutants.

LITERATURE

Literature Survey

The literature search for information pertinent to the task of this project was conducted among military, academic and industrial publications of past work. No articles dealing directly with the specific subjects of solvation, neutralization, or reduction of Explosive D/water slurry were found. However, many articles, which treated the behavior of polynitro aromatics having chemical structure similar to that of Explosive D, were helpful in formulating the experimental approaches to be considered.

References which pertain more specifically to reactions of amines with picric acid and picrates are reviewed later in the weak base reaction section of the chapter on experimental work. Topics of nitro and polynitro aromatic compounds in general are reviewed and discussed in the following order: (1) complexing, (2) reduction, (3) catalytic hydrogenation, (4) degradation reactions, (5) nucleophilic substitutions, (6) reaction mechanisms, and (7) summary of literature survey. For further details of these surveys, see AED Report No. 23-82, Yellow D Solvation Conversion Project, Final Report, August, 1982, by Ammunition Equipment Directorate, Tooele Army Depot, Tooele, UT

Summary of Literature Survey

The literature survey showed that polynitroaromatic compounds do react with alkalies by nucleophilic displacement and substitution of the nitro groups, which are the groups responsible for the explosive nature of such compounds.

Sufficient analytical work was cited to verify that the alkaline conversion proceeds through ionic transition states such as the Meisenheimer complex.

The reaction products of nitro compounds and alkali are generally more soluble in hydroxy and amino solvents than in other common solvents.

Even mildly basic alkalies such as organic amines react with nitroaromatics to destroy their explosive nature by displacement, substitution, complex formation, ring cleavage, and degradation.

EXPERIMENTAL WORK

Introduction

Two basic approaches were taken to solve the disposal problem of Yellow D/water slurry. The first methods considered would alter the explosive/water mixture physically by adding a solubilizing agent or diluent which would not change the explosive chemically. The second method studied would alter the explosive chemically. Chemical conversions of Yellow D would yield a more soluble but less sensitive product. The conversion product must be easy to transport, safe to burn in existing rotary kiln furnaces at WADF without producing harmful emissions, and must remain in solution even at low temperatures. The six specific methods that were considered during the experimental work are listed below.

1. Suspension Method: Addition of a gelling agent to the Yellow D/water slurry to keep the Yellow D in suspension, enabling the slurry to be processed and transported without sedimentation and plating-out.

2. Solid Dilution Method: Addition of diatomaceous earth or other diluting mediums to the Yellow D/water mixture while hot, to produce a slurry with low explosive density or a cake which can be burned safely.

3. Solvation Method: Dissolution of Yellow D/water mixture in an appropriate organic solvent or a combination of solvents, retaining the Yellow D in a true solution which can then be transported by pumping it through the process system or by using the transport tankers.

4. Chemical Conversions: Conversion of Yellow D into a combustible but less sensitive product, by a simple chemical reaction to give a product which can then be dissolved in an appropriate solvent.

5. Catalytic Hydrogenation: Reduction of Yellow D partially or completely to polyamino compounds, by a catalytic reduction.

6. Electrolytic Reduction: Electrolytic reduction of the nitro groups of Yellow D would be achieved by electrolysis of the explosive dissolved in an appropriate electrolyte.

Suspension Study

Suspension tests were made with hydroxyethylcellulose gelling agent (puchased from Gulf Chemical Co.) to determine whether the gelling action would inhibit the agglutination of large masses of Yellow D solid, and prevent Yellow D from plating-out on process equipment.

In the first batch test, ten grams of reclaimed Yellow D powder was added to 30 ml of water and heated until a clear yellow solution was obtained. One gram of hydroxyethylcellulose was then added to the solution and stirred vigorously to produce a homogeneous mixture. The mixture was heated in a water bath for 30 minutes at 75°C. The resulting clear solution was removed from the water bath and allowed to cool to room temperature. Fine needle shaped crystals began to form slowly within the solution. Recrystallization was completed in 30 minutes.

In the second experiment, the solution of Yellow D/water/hydroxyethylcellulose was prepared as described in the first test. To this solution, 4 grams of n-butylamine and 10 ml of methanol were added. This second mixture was heated for one hour at 75°. A clear yellow sclution was produced again and allowed to cool. As the mixture cooled to room temperature, Yellow D crystals did not form immediately. However, when the product was reexamined on the next day, Yellow D dendrite crystals had formed on the walls of the reaction flask.

Although the gelling agent did inhibit immediate precipitation of Yellow D, the gradual build up of crystals indicated that the suspension created by the gelling agent only served to slow down the plating process. Table 2 summarizes the experimental data.

TABLE 2 SUSPENSION TEST

TEST NO.	EXPLOSIVE D (gm)	WATER (ml)	GELLING AGENT (gm)	AMINE (gm)	METHANOL (ml)	OBSERVATIONS
1	10	30	1	-	-	a- heated the mixture to 75 C, producing a clear solution.
						b- upon cooling to room temperature the solution was immediately crystallized.
2	10	30	1	4	10	a- heated the mixture to 75 C, producing a clear solution.
						b- when the solution was cooled to room temperature, it did not crystallized.
						c- allowed to stand over night. when reexamined next morning, needle shaped crystals were growing on the inside surface of the flask.

Solvation Study

Solvation tests were conducted to select an organic solvent which, when added to the Yellow D/water mixture, would enhance the solvation characteristics, and thus alleviate the problem of recrystallization and the subsequent plating-out of explosive onto the process equipment.

The first test of this experiment was to find a group of candidate solvents that would dissolve the dried Yellow D at room temperature (25°C). Mainly three classes of organic solvents were investigated: (a) hydroxy solvents, (b) amino solvents, (c) hydrocarbons.

The second test was conducted to select the solvent from among the candidates that would best dissolve the Yellow D/water mixture. A test was conducted to determine the solubility behavior as a function of mixture component ratios. Finally, the solutions selected were subjected to zero degrees Celsius to determine the low temperature stability. The experimental procedures for each test and their results are discussed briefly below.

1. Dried Yellow D. Two grams of solvent was added slowly to two grams of Yellow D in a test tube. The mixture was shaken vigorously, then set aside to facilitate the settling of undissolved explosive on the bottom of the test tube. The result was inspected visually. This procedure was repeated until a group of solvents was selected. Fifteen solvents were tried. They were: (a) five hydroxy solvents: methanol, ethanol, 2-propanol, ethylene glycol and glycerin; (b) five amino solvents *tert*-butylamine, aniline, *n*-butylamine, *n*-hexylamine and isopropylamine; (c) two different concentrations of acetic acid; (d) one hydroxylamino solvent: ammonium hydroxide; (e) one carbonyl solvent: acetone; (f) one sulfoxide solvent: dimethylsulfoxide; and (g) water.

Among the solvents tried, amino solvents showed superior solvation behavior, while dimethylsulfoxide also gave good results. Suprisingly, aniline showed very weak solubility behavior toward Yellow D. All hydroxy solvents gave very little or no dissolution. Results from this first experiment are summarized in Table 3.

2. Yellow D/Water/Amines. Two grams of Yellow D was added to four grams of water in a test tube which was placed in a water bath. The temperature of the water bath was maintained at 95°C. When the Yellow D was completely dissolved, the test tube was removed from the water bath and placed in an ice bath. The excess water was pipetted off the top of the mixture when the recrystallization of Yellow D was completed. Two grams of amino solvent was then added to the Yellow D/water mixture, which was shaken vigorously, and set aside. The result was observed and noted. This procedure was repeated until the best solvent was chosen from the amino solvents tried. Four amino solvents and dimethlsulfoxide were tried. Yellow D/water slurry dissolved well in tert-butylamine, n-butylamine, and isopropylamine, producing clear amber solutions. However, n-hexylamine gave an amber solution with some emulsification. Dimethylsulfoxide did not dissolve Yellow D/water slurry completely. The results are summarized in Table 4.

3. Dried Yellow D/n-butylamine. One-gram to six-gram portions of n-butylamine were slowly added to bottles each containing ten grams of Yellow D powder. The bottles were shaken vigorously, and set aside to determine an optimum solubility ratio for Yellow D in n-butylamine at 25°C (room temperature). Tests showed that six grams of n-butylamine completely dissolved ten grams of Yellow D powder, producing a clear amber solution.

4. Yellow D/n-Butylamine/Methanol. An investigation was conducted on the solubility increase induced by addition of methanol to the Yellow D/*n*-butylamine mixture. Yellow D/*n*-butylamine mixtures were prepared as described in experiment No. 3. Two to twelve gram portions of methanol were added to the samples, which were shaken vigorously, and set aside. Results showed that there was no marked gain in solubility by addition of methanol to the mixture of Yellow D/*n*-butylamine.

5. Yellow D/water/n-butylamine. One to three gram portions of Yellow D and three to seven gram portions of water were combined at room temperature. Quantities of 0.37 grams to three grams of *n*-butylamine were added to the Yellow D/water mixtures, shaken vigorously, and set aside to observe the solubility behavior of solutions as a function of the mixture component ratios. Results showed that a complete solvation of Yellow D/water slurry was achieved when one part of Yellow D powder was dissolved in three parts of water and three parts of *n*-butylamine. In one case, one part of Yellow D was dissolved in four parts of water and one part of *n*-butylamine, producing a single phase solution. When more Yellow D than *n*-butylamine was used, it produced a solution with some undissolved solid in test tubes. Thus, tests indicated that as long as the Yellow D/*n*-butylamine ratio was maintained at one to one, the solution could dissolve up to four parts of water iwthout sedimentation. The results of this test are summarized in Table 5.

6. Low Temperature Test. Yellow D/water/*n*-butylamine solutions, similarly prepared as described in experiment 5 above were placed in an ice bath for one hour to observe the solubility behavior changes caused by the lowering of temperature. During the lowering of the solution temperature from 25°C to 0°C, no recrystallizations were observed and no phase changes were detected for all samples tested. During the lowering of the solution temperature from 25°C to 0°C, no recrystallizations were observed and no phase changes were detected for all samples tested. Results of this test are summarized in Table 6.

TABLE 3

SOLUBILITY TESTS FOR RECLAIMED DRIED YELLOW D IN VARIOUS SOLVENTS

Test No.	Yellow D Wt (g)	Solvent Name	Solvent Wt(g)	Wt% of Yellow D	Observed Solubility
1	3	H_2O	5	37.5	Very slight
2	2	MeOH	5	28.57	Very slight
3	2	EtOH	5	28.57	Very slight
4	2	*i*-PrOH	5	28.57	Very slight
5	3	*t*-Butylamine	5	37.5	Complete
6	2	Aniline	5	28.57	Partial
7	3	Isopropylamine	5	37.5	Complete
8	2	NH_4OH (15M)	5	28.57	Partial
9	3.2	*n*-Butylamine	5	39.02	Complete
10	3	*n*-Hexylamine	5	37.5	Complete
11	2	Acetone	5	28.57	Very slight
12	3.15	DMSO	5	38.65	Complete
13	2	Ethylene glycol	5	28.57	Very slight
14	2.2	Glycerin	5	28.57	Partial
15	2.1	Acetic Acid (50%)	5	28.57	Insoluble
16	2.1	Glacial Acid acid	5	28.57	Insoluble

Note: Solubility tests were conducted at 25°C.

Abbreviations:

H_2O	Water
MeOH	Methanol
EtOH	Ethanol
i-PrOH	2-Propanol
NH_4OH	Aqueous ammonia
DMSO	Dimethylsulfoxide

TABLE 4

SOLUBILITY TESTS FOR RECLAIMED YELLOW D/WATER SLURRY IN AMINES

TEST NO.	YELLOW D (gm)	H_2O (gm)	SOLUENT	gm	OBSERVATION
1	3	5	TBA	5	Complete, clear amber solution
2	3.2	5	MBA	5	Complete, clear amber solution
3	3.5	5	IPA	5	Complete, clear amber solution
4	3	5	NHA	5	Complete, some emulsification
5	3.15	5	DMSO	5	Partial

Abbreviations: TBA tert-butylamine

NBA n-butylamine

IPA isopropylamine

NHA n-hexylamine

DMSO dimethyl sulfoxide

TABLE 5

SOLUBILITY TESTS FOR YELLOW D/nBA/H2O MIXTURES

TEST NO.	YELLOW D (gm)	H2O (gm)	nBA (gm)*	OBSERVATION
1	1	3	3	Complete, single phase
2	2	3	2	Complete, 2 phase
3	2.5	3	2	Complete, 2 phase
4	3	3	2	Complete, 2 phase
5	3.5	3	2	Small insoluble solids, 2 phase
6	1.5	3.5	1.0	Complete, single phase
7	1.5	3.5	1.5	Complete, 2 phase
8	2	3.5	1.5	Small insoluble solids, 2 phase
9	1	4	1	Complete, single phase
10	1.5	4	1	Incomplete, 2 phase
11	1	4.5	0.5	Incomplete, 2 phase
12	2.5	7.1	0.37	Incomplete, 2 phase
13	2.5	7.1	0.87	Incomplete, 2 phase
14	2.5	7.1	1.37	Incomplete, 2 phase
15	2.5	7.5	1.5	Partial
16	2.5	7.5	2.25	Complete

* n-butylamine

TABLE 6

SOLUBILITY TESTS FOR RECLAIMED YELLOW D/nBA/H_2 AT LOW TEMPERATURES

TEST NO.	YELLOW D (gm)	H_2O (gm)	nBA (gm)	SOLUBILITY RT (25°C)	SOLUBILITY ICE BATH (0°C)	OBSERVATIONS
1	1	4.5	3	Complete	No precipitation	Single phase
2	1.5	4.5	3	Complete	No precipitation	Single phase
3	2	4.5	3	Complete	No precipitation	2 phase
4	2.5	4.5	3	Complete	No precipitation	2 phase
5	3	4.5	3	Complete	No precipitation	1 phase
6	1	4.5	2.25	Complete	No precipitation	2 phase
7	1.5	4.5	2.25	Complete	No precipitation	2 phase
8	2	4.5	2.25	Complete	No precipitation	2 phase
9	2.5	4.5	2.25	Complete	No precipitation	2 phase

Effect of Aging at Ambient Temperature

This test was conducted to observe the room-temperature effect of aging on viscosity, recrystallization, sedimentation, and stability of Yellow D/amine/water/methanol solutions. The solution were prepared by adding amine to the Yellow D/water mixture followed by the addition o methanol.

During the addition of amine to the Yellow D/water mixture, some evolution of gas was noted indicating that even at room temperature the initial displacement reaction was occuring wherein the ammonium ion was replaced by an _n_-butylammonium ion.

When the evolution of gas ceased, methanol was added to the mixture, producing an amber colored solution. Thereafter, the slow degradation reaction was indicated by the gradual darkening of the solution. Six months of aging did not change the viscosity of the solution and no recrystallizations or sedimentations were detected. A summary of mixing ratios and observations is given in Table 7.

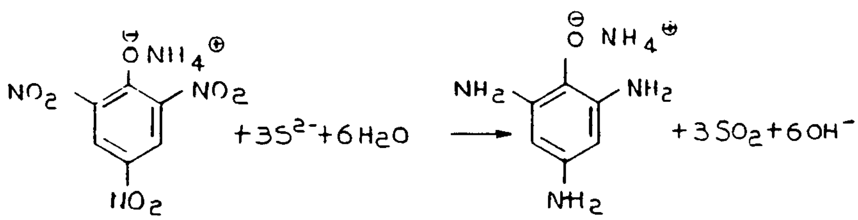
TABLE 7

AGING STUDY OF YELLOW D/AGENTS

TEST NO.	YELLOW D (gm)	NBA (gm)	ISO-PA (gm)	H_2O (gm)	MeOH (gm)	REACT TEMP (°C)	REACT (DATE)	SOLUBILITY	OBSERVATION
B-1	30	30	-	15	30	27	10/26/81	Complete	Solution
B-2	30	20	-	15	30	"	10/26/81	Complete	Solution
B-3	30	15	-	15	30	"	10/26/81	Incomplete	Solution
M-1	10	10	-	-	-	"	2/20/82	Complete	Viscous Syrup @5/21/82
M-2	5	10	-	-	-	"	2/20/82	Complete	Solution @5/21/82
M-3	5	15	-	-	-	"	2/20/82	Complete	Solution @5/21/82
M-4	3	12	-	-	-	"	2/20/82	Complete	Solution @5/21/82
SK-1	5	-	5	-	-	"	5/10/82	Complete	Solution @5/21/82
SK-2	5	-	10	-	-	"	5/10/82	Complete	Solution @5/21/82
SK-3	5	-	15	-	-	"	5/10/82	Complete	Solution @5/21/82
SK-4	5	-	20	-	-	"	5/10/82	Complete	Solution @5/21/82

Strong Base Reduction

Strong base reduction of Yellow D was examined to determine the feasibility of producing a compound with increased solubility and lowered sensitivity. The experiment was conducted using sodium sulfide (NA_2S). Briefly, ammonium sulfide $(NH4)_2S$ was also investigated with similar results. The reaction reduces the polynitro aromatic Yellow D to a more stable polyamine-substituted aromatic compound. A simplified overall equation for the reduction reaction is given below.



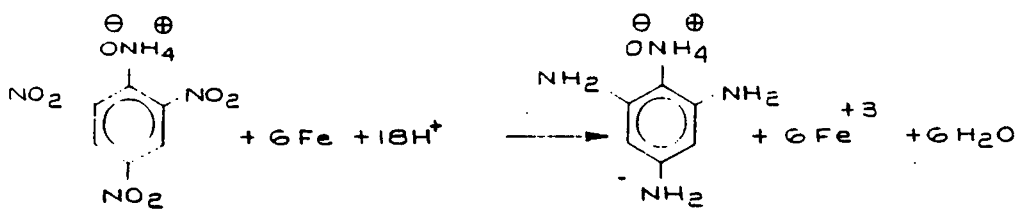
The reaction was carried out in a 2000-ml three-neck round-bottom flask equipped with a water-cooled condensor, a thermometer, a mechanical stirrer, and a heating mantle. Sodium sulfide was dissolved in cold water in the flask, and Yellow D was added slowly to the sodium sulfide solution.

Initially, the reaction was strongly exothermic, but thereafter, the reaction settled down and continued smoothly to the end. The product was a dark brown solution which, upon cooling, became a slurry with solids of a definite crystalline form. The dried product was completely soluble in cold water. Table 8 summarizes the reaction runs, showing various reaction conditions and reactant concentrations. A run made with ammonium sulfide was essentially identical to the reaction with sodium sulfide, but was slightly less vigorous.

A preliminary impact sensitivity test was conducted on the dried solids. The test indicated that the dried product was insensitive to impact. Detailed discussion of this impact test is given later in the Hazard and Safety section. Test results are summarized in Table 9.

Acid/Metal Reduction

A strong acid/metal reduction of Yellow D was investigated using (1) hydrochloric acid/iron, and (2) hypophosphorus acid. A simplified overall reduction reaction of Yellow D is shown below.



Reaction apparatus employed for this experiment was similar to the one used in the previous section. Hot water (300 ml) was added to 47 grams of Yellow D in a 1000 ml flask. Then, 104 grams of iron filings and 50 ml of hydrochloric acid (6N) were added to the Yellow D/water mixture. The flask was placed in a water bath which was heated by a proportional-temperature-controlled heating mantle. The reaction temperature was maintained at 97°C for one hour. The resulting dark brown slurry was cooled to room temperature, and filtered to remove solids. Liquid obtained was neutralized with dilute sodium hydroxide, and extracted with ethyl ether to recover the product. Evaporation of the ether gave a brown oily product interspersed with yellow colored crystalline solids. Results are summarized in Table 10.

For the Yellow D/hypophosphorus acid reaction, the following procedure was used. First, 2.5 grams of hypophosphorus acid and 2.3 grams of water were added to a 100-ml round-bottom flask, and as the mixture was swirled, 5 grams of Yellow D was added to the flask. After 10 minutes of swirling, an additional 1.8 grams of acid was added to facilitate further solvation of the Yellow D.

The solution was heated to 92°C for 30 minutes, and then removed from the water bath and allowed to cool to room temperature. The resulting slurry was extracted first with ethyl ether, producing an amber colored solution. Evaporation of the ether produced red solids. The residue from the first extraction was washed with methanol giving a dark brown solution. When the methanol was evaporated, an oily product was obtained. Test results are summarized in Table 10.

TABLE 8

STRONG BASE REACTIONS

No.	YD (gm)	H2O (gm)	Na2S.9H2O (gm)	ADDITION SEQUENCE	REACTION TIME (hour)	REACTION TEMP	OBSERVATIONS
SB1	400	400	100	Na2S/H2O/YD	4 H	60-96°C water bath	a-during the addition of YD temperature increase of 50°C was noted. b-product was air dried in a as pan. c- the air dried product was compeletly dissolved in an equal amount of cold water.
SB2	300	600	200	H2O/Na2S/YD	4½ H	61-94°C water bath	a-dissolved Na2S in H2O and then added Na2S slowly while the vessel was in cold water bath. b- temperature increase of 25°C was noted c-air dried product behave the same as above.
SB3	200	500	80	H2O/Na2S/YD	3 H	88-93°C water bath	a-exothermic temp increase noted from 27°C to 54.8°C b-all other behaviors are the same
SB4	200	500	200	YD, H2O/Na2S	5 H	73-96°C water bath	a-within 10 minuts the reaction tem. reached 96°c exotherm b-the air dried product was subjected to the solubility tests; acetone-incomplete, gummy residue water-complete, dark brown solution MeOH-incomplete Et2O-partial,yellow solution/gummy residue
SB5	100	300	30	H2O/Na2S/YD	2 H	95°C waterbath	a-procedure was the same as the exp SB2 b-product was dissolved in cold water completely
SB6	200	200	100	same	2 H	91°C waterbath	a-same as above
SB7	100	150	100	same	2 H	96°C same	a-same as above
SB8	150	150	50	same	2 H	93°C same	a-same as above
SB9	200	250	50	same	4 H	95°C same	a-same as above
SB10	200	250	20	same	3 H	93°C same	a-same as above
SB11	200	250	10	same	1½ H	100°C same	a-same as above
SB12	200	500	200	same	1 H	95°C same	a-solubility tests; for the product acetone-partial cold-water-complete MeOH-partial benzene-insoluble Et2O-partial
SB13	20	10	ammonium sulfide 10		9 H	75°C same	a- 20gm of nBA and 20gm of MeOH were added to the mixture before the reaction b-product is a dark brown solution c-air dried product dissolved completely in cold water

TABLE 9

PRELIMINARY IMPACT TESTS FOR STRONG BASE REACTION PRODUCTS

CONDITIONS					RESULTS 1), 2)									
TEST RUN NO.	YD (gm)	H_2O (gm)	Na_2S (gm)	Na_2S (%)	1	2	3	4	5	6	7	8	9	10
1	200	200	32.78	8	+	+	+							
2	100	150	32.78	11.6	+	+	+							
3	200	250	16.39	3.5	+	+	+							
4	200	250	6.24	1.4	+	+	+							
5	50	100	48.39	24.4	—	—	—	—	—	—	—	—	—	—
6	*			standard	+	+	+							

Notes: 1). Positive signs indicate detonation, reaction or burn.

2). Negative signs indicate no detonation, reaction nor burn.

3). Samples were air dried first, then vacuum-oven dried for two hours at 70°C and -25 psi, producing lumps.

4). Impact tests were conducted, using the maximum height of 240 cm.

5). Tests were conducted at Picatinny Arsenal laboratory, Dec. 1-11, 1981

* Explosive D was used as a standard.

YD is Yellow D Explosive.

TABLE 10

YELLOW D/ACID-METAL REDUCTION

RXN RUN NO.	YELLOW D (gm)	Fe FILING (gm)	HCl (6N) (ml)	RXN TEMP (C)	RXN TIME (Hour)	OBSERVATION
Y2	45	100	45	90-97	1	Brown Solution
Y3	45	100	45	90-97	2	Brown Solution
Y5	47	105	50	93-97	2	Brown Solution
Y6	45	100	50	97	1.5	Brown Solution
Y7	47	104	50	92-97	2	Brown Solution
Y8	45	105	50	92-97	4	Brown Solution
* P1	5	10	7	92	0.5	Dark Solution

* Hypophosphorus acid was used.

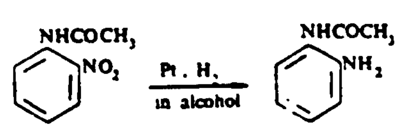
Catalytic Hydrogenation

A catalytic reduction of Yellow D, using palladium on finely divided carbon (from Degusse Corp., Chemical Division), was investigated. The overall reduction reaction was similar to the one already outlined in the two previous sections.

A brief discussion of hydrogenation using a bench model Parr apparatus is given here. Yellow D, methanol, and palladium/carbon catalyst were charged into a stainless steel hydrogenation vessel. Hydrogen gas was supplied from a storage tank. The initial hydrogen pressure in the reaction vessel was adjusted to 60 psi. The mixture was shaken mechanically to induce the hydrogenation of Yellow D until the pressure in the reaction vessel decreased to less than 20 psi. The shaking apparatus was stopped, the hydrogen pressure in the vessel was increased again to 60 psi, and the shaking was resumed. This procedure was repeated until the uptake of hydrogen gas by the reactant ceased.

The reacted material was decanted from the vessel and the mixture was filtered to recover the product. Table 11 summarizes the results of this experiment. A simplified hydrogenation/reduction is given in the following equation.

2-Nitro-*p*-xylene   2-Amino-*p*-xylene



o-Nitroacetanilide   *o*-Aminoacetanilide

TABLE 11

SUMMARY OF CATALYTIC HYDROGENATION

Explosive D (g)	Pd/Carbon (g)	MeOH (ml)	Pressure (psig)	Reaction Time (minutes)	Observed Result
10	0.5	60	60	70	3 Uptakes: 60-32.5 psi 60-34 psi 60-52 psi
5	0.5	60	60	55	2 Uptakes: 60-17 psi 60-50 psi

Weak Base Reaction

The solvation study discussed previously, and a subsequent literature survey showed that n-butylamine was capable of solubilizing and desensitizing Yellow D through (a) formation of charge transfer complexes, (b) nucleophilic substitution reactions, and (c) irreversible degradation reactions of Yellow D in amine solution.

Although no specific previous work on the reaction of Yellow D/water slurry with n-butylamine has been reported, many papers have appeared in chemical journals on the subject of the reactions of picric acid and other substituted polynitro aromatic compounds, with various nucleophilic reagents in ionizing solvents such as methanol and acetonitrile. Some of the more pertinent papers are reviewed here.

Addition complexes are formed when picric acid, styphnic acid, picrolonic acid, di- and trinitro derivatives of benzene, including 1,3,5-trinitrobenzene and 2,4,6-trinitrotoluene (TNT) are reacted with amines and amino compounds. These complexed derivatives are generally more soluble in hydroxylic solvents than are unreacted polynitro aromatic compounds.[4,5]

Reactions of di- and trinitrobenzene with several bases of the amine type have been reported by Lewis and Seaborg[6]. They postulated a several step reaction mechanism: (a) the direct loss of a hydrogen ion from one of the hydrogen atoms of the polynitro compounds, i.e., displacement of one of the three hydrogens of the trinitrobenzene ring, or the use of one of these hydrogens to form a hydrogen bond with the

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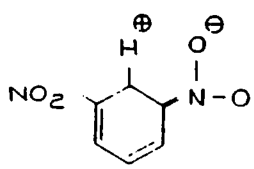
[4]Dimroth, Bamberger, Ann. Chem., 438 (1924), 67.

[5]Knorr, Ibid., 307 (1899), 183.

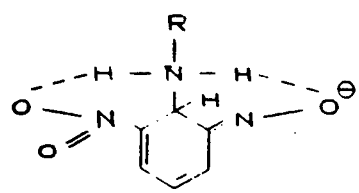
[6]Lewis, Seaborg, J. Am. Chem. Soc, 62 (1940), 2122.

base; (b) the direct addition of a base to one of the ring carbons that is not attached to a nitro group; (c) the attachement of the base to one of the nitrogens.

One of the several important structures contributing to the resonance state of m-dinitrobenzene is represented by formula V. To account for the fact that ammonia reacts readily with dinitrobenzene, Lewis and Seaborg proposed formula VI. This represented inadequately a complex resonating system with double chelation, in which two hydrogens acted as hydrogen bond donors between nitrogen and oxygen atoms. While formula V represented a completely planar structure, formula VI did not.



(V)



(VI)

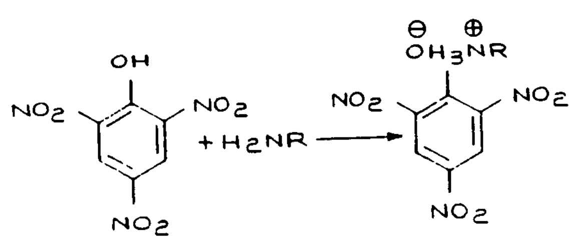
If the energy of double chelation is responsible for the strong attachment of ammonia, less neutralization of m-dinitrobenzene is expected by similar bases with only one hydrogen donor and much less with no hydrogen donor in the base. This was found to be the case. Methylamine, which like ammonia is capable of double chelation, gave a color of approximately the same quality and intensity of ammonia, but the two stronger bases, dimethylamine, which is capable of only one chelation, and triethylamine, in which only nitrogen chelation is

possible gave no color at all with m-dinitrobenzene. With trinitrobenzene, ammonia and the three amines all produced color solutions which increased in intensity with lowering of temperature.

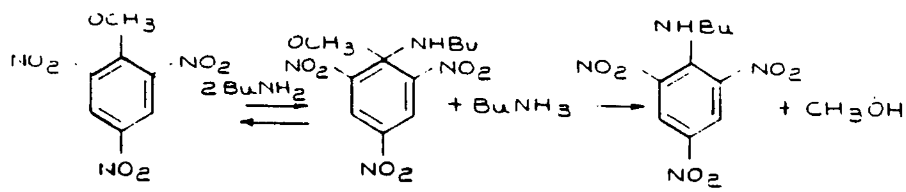
Although trinitrobenzene was a much stronger acid than dinitrobenzene, the same effect of single and double chelation was found, i.e., under similar conditions, the intensity of the color was least with triethylamine, greater with demethylamine and still greater with methylamine and ammonia.

Lewis and Seaborg's experiments indicated that this phenomenon was repeated when dinitrobenzene, sym-trinitrobenzene, trinitrotoluene, trinitroxylene or trinitromesitylene were reacted with ammonia, a primary amine, a secondary amine or a tertiary amine. Thus it was deduced that the stability of the colored compounds was greatly enhanced by chelation, and especially by double chelation in which hydrogens of an alphatic amine were attached to oxygen of the nitro groups.

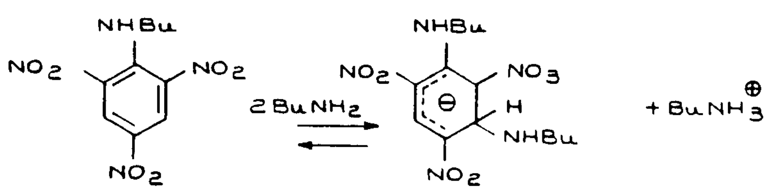
Picric acid reacts with amines to yield molecular compounds (picrates), which usually possess characterictic melting points. Most picrates have a composition of one mole of amine and one mole of picric acid. The picrates of amines, particularly of the more basic amines, are generally more stable than the molecular complexes formed between picric acid and the hydrocarbons.



Fyfe and others reported on the reaction pathway in the nucleophilic aromatic substitution reaction of 2,4,6-trinitroanisole with n-butylamine in a solvent mixture of dimethylsulfoxide and methanol (50/50). Their experiment indicated that when excess n-butylamine was used, the resulting products were methanol and substituted aniline as shown in the following equation.[7]

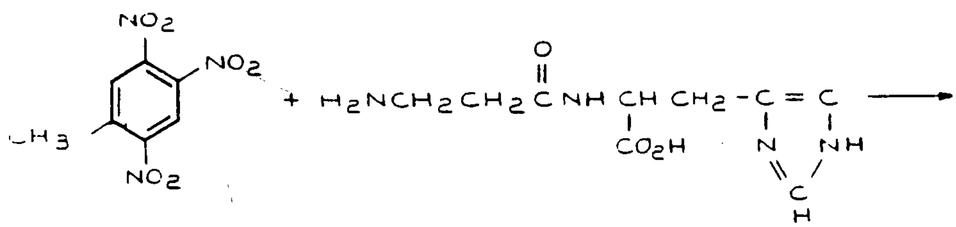


Furthermore, the second adduct reaction was detected as a sigma complex from the attack of n-butylamine on C-3 of the neutral product.

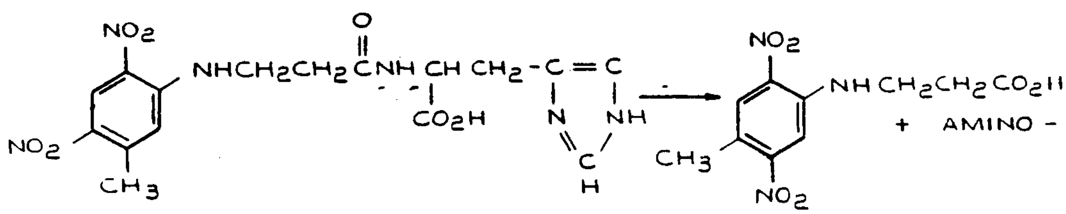


[7]Fyfe, et al, Can. J. Chem., 55 (1977), 1468.

Barger and Tutin reported that when trinitrotoluene was reacted with amino acid boiling in a dilute alcoholic solution, the amino acid became attached to the benzene ring by its amino group in replacement of a reactive nitro group which was eliminated. The resulting compound was N-dinitrotolylamino acid. The overall reaction was shown to proceed as follows.[7]



(II)



(III)

[7]Barger, Biochem. J., 12 (1918), 4029.

Matsunaga and Usui reported that the reaction of _o_-aminobenzoic acid and picric acid was found to produce four different kinds of adducts. These were a stable yellow salt (1:1), (formed by the proton transfer from the picric acid to the _o_-aminobenzoic acid molecule), two red complexes (consisting of the _o_-aminobenzoic acid molecule, and its protonated ion), and the picrate ion.[8]

It was shown that ammonia, primary amine, secondary amine, or tertiary amine would react with polynitroaromatic compounds producing stable compounds, consisting of charge transfer complexes and nucleophilic substituted adduct compounds.

Because it was found that _n_-butylamine was an excellent solvation agent for Yellow D as discussed in the solvation section, it was logical to use this chemical not only as solvation medium but also as a desensitizing agent by reacton of Yellow D with _n_-butylamine at an elevated temperature to expedite the solvation/conversion process.

[8]YMatsunaga, Usui, Bull. Chem. Soc. Jpn., 53, (1980), 53.

Experimental Procedure for Weak Base Reaction

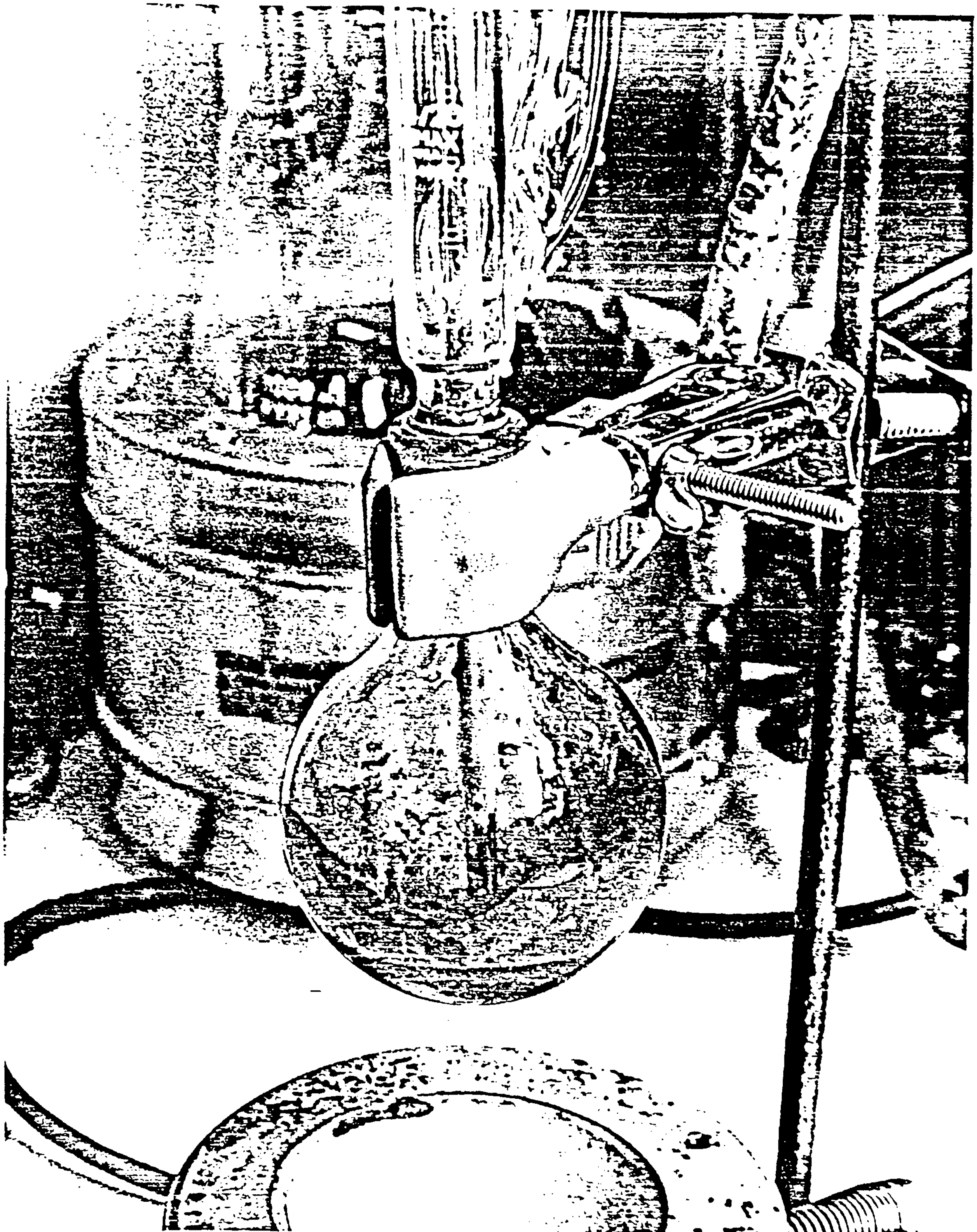
Yellow D in the form of crystalline ammonium picrate or reclaimed Yellow D powder was reacted with n-butylamine in a water and methanol mixture in a round bottom three neck flask. The reaction flask was equipped with a thermometer and a water cooled reflux condensor. The heating of the reaction vessel was accomplished by placing the flask in the water bath on a temperature proportionate controlled hot plate.

The reaction temperatures and times were varied from 25°C to 90°C and from 30 minutes to 10 hours respectively. Yellow D and n-butylamine ratios were varied at 1:1, 1:2, 1:3, and 1:4 by weight in order to determine the optimum reactant ratio. Also, to simulate the washout process at WADF, some of the experiments were conducted by first producing the Yellow D/water slurry.

The general experimental procedure was as follows. Yellow D was added to water in the flask and was shaken well to produce a uniform slurry. The color of this slurry was a bright yellow. n-Butylamine was added it began dissolving some of the Yellow D, producing a light amber colored solution.

The temperature of the mixture was gradually increased to the refluxing temperature. As soon as the temperature began to rise, a vigorous evolution of gases was observed, and the solution darkened from amber to brown. The evolution of gases was completed in approximately 10 minutes. Thereafter the reaction continued smoothly to the end. Figures 4, 5, 6, and 7 illustrate the sequence of the dissolution and conversion.

The reacted material was removed from the water bath and a predetermined amount of methanol was added. The product was decanted into a beaker for cooling. The product was a brown liquid, and had a strong amine odor which was due to the excess n-butylamine used. The vigorous release of ammonia during the reaction indicated that the



DISSOLUTION SEQUENCE OF YELLOW D SLURRY
AT START OF n-BUTYLAMINE ADDITION

FIGURE 4

DISSOLUTION SEQUENCE OF YELLOW D SLURRY IMMEDIATELY AFTER ADDITION OF n-BUTYLAMINE

FIGURE 5

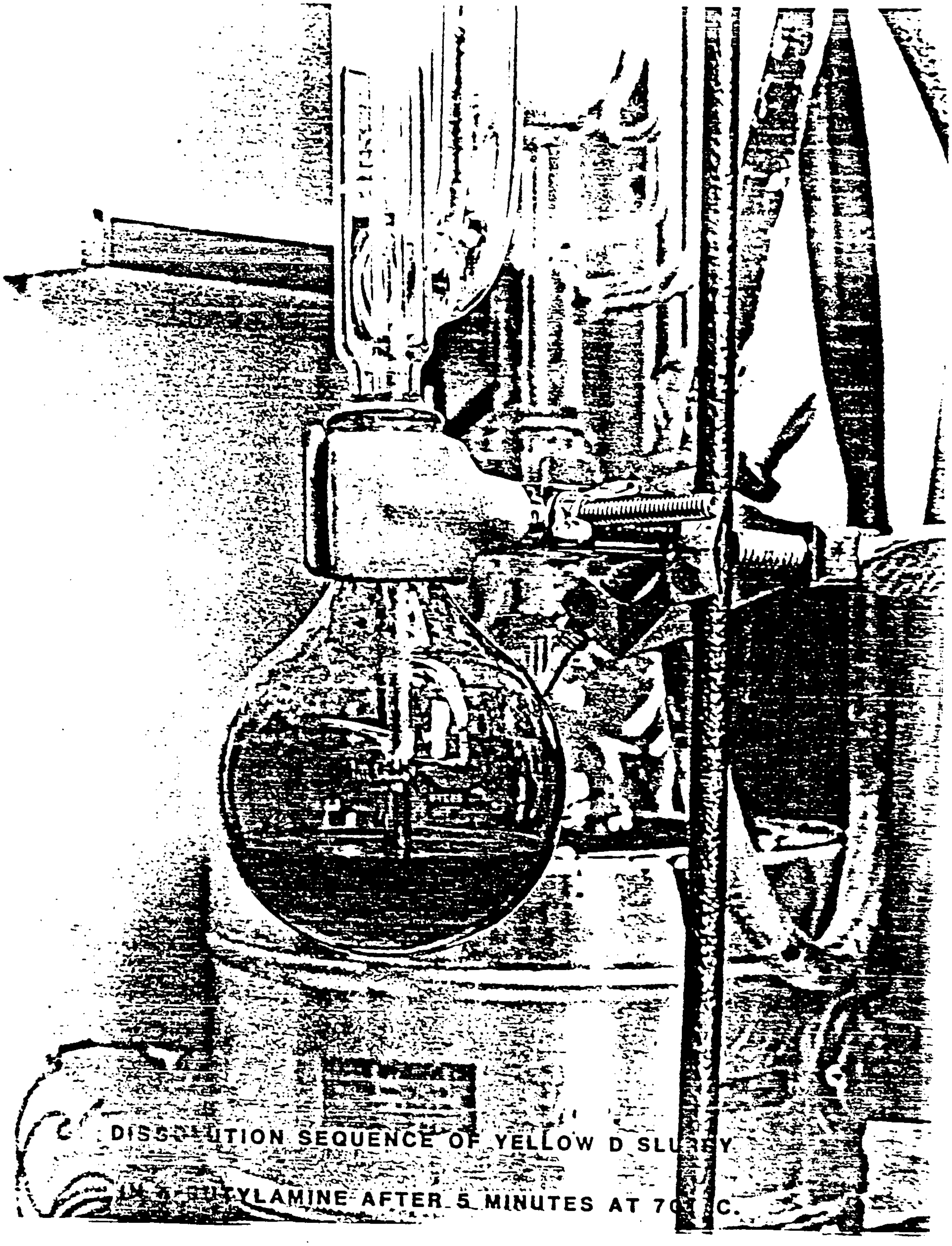
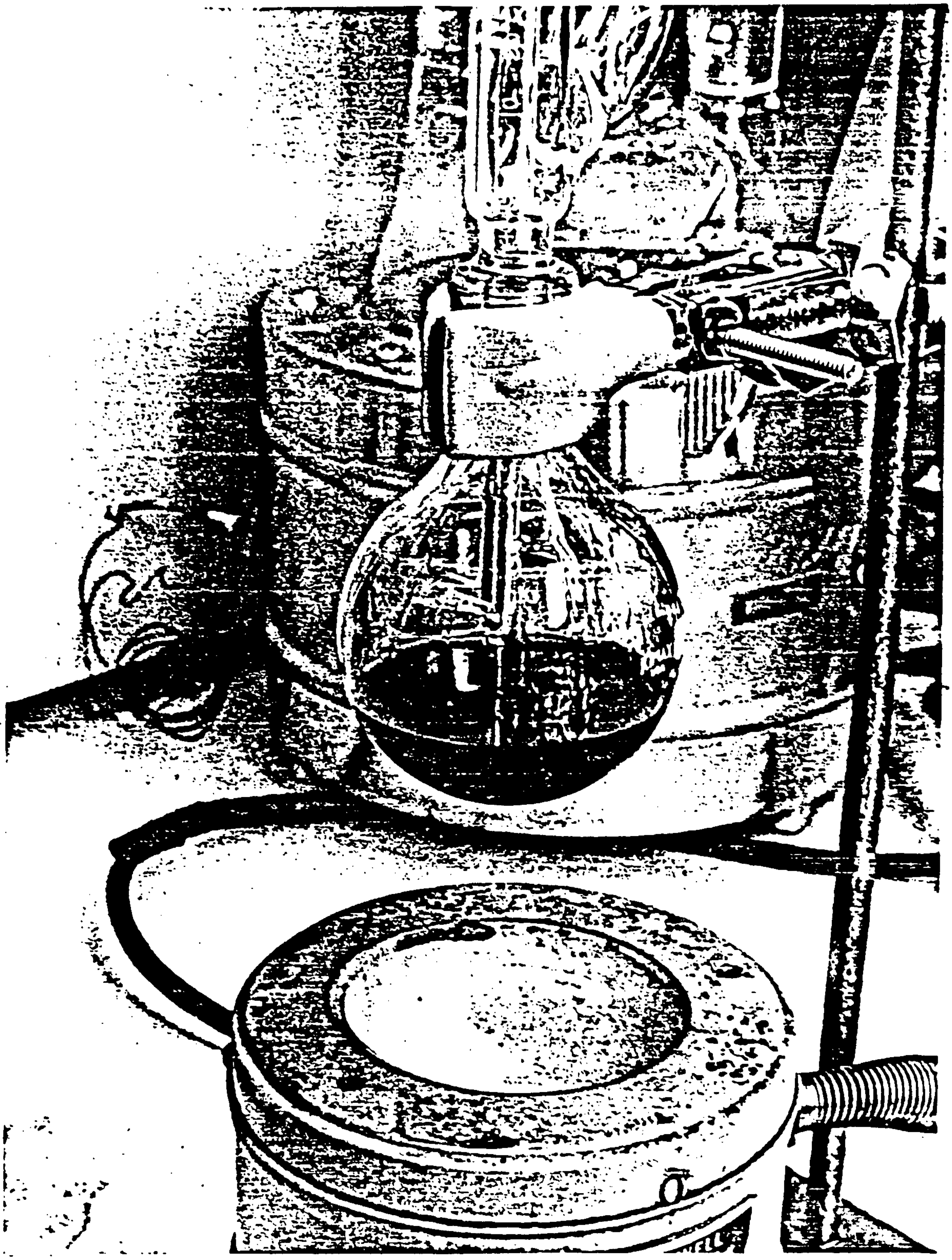

DISS UTION SEQUENCE OF YELLOW D SLU Y
LAMINE AFTER 5 MINUTES AT 7 C.

FIGURE 6



DISSOLUTION / CONVERSION SEQUENCE OF YELLOW D SLURRY IN n-BUTYLAMINE AFTER 1 HOUR AT 70° C.

FIGURE 7

initial reaction of Yellow D/water slurry with excess *n*-butylamine was an ammonia/*n*-butylamine displacement reaction. Thus, the major product in the brown solution was *n*-butylammonium picrate. Some degradation product were detected in the solution at that point. This fact was verified by gas chromatographic-mass spectrometric analyses. Furthermore, degradation reactions continue as the conversion product ages, due to the excess amine environment of the solution. A summary of this experimental work is given in Table 12.

Summary of Experimental Work

Six experimental methods were considered. Physical methods, were examined as a means to maintain the explosive in solution during transport and disposal, whereas chemical methods, employing more elaborate techniques of reduction chemistry, modify the explosive chemically not only to maintain it in solution but to produce a combustible and non-detonable fuel.

Two methods were mentioned but not examined experimentally beyond brief theoretical discussions: A solid dilution method would have mixed the Yellow D/water mixture with a large amount of diatomaceous earth, producing a slurry which could be dried, transported, and disposed of easily by incineration. The dilution of the explosive in a matrix of inert (silicate) material would allow a relatively safe incineration due to the low explosive density per unit mass. The main problem with the solid dilution method lies in handling large volumes of diatomaceous earth at the washout stage and removing it at the incineration stage. The second method was an electrolytic reduction. The product from the electrolytic reduction would be similar to the products obtained from the reduction of Yellow D by strong base, acid/metal, and palladium/carbon. The electrolytic reduction of Yellow D and related explosives, is promising, and could be pursued further at some later date. This method would require a different facility than that at WADF.

TABLE 12

YELLOW D/n-BUTYLAMINE REACTION SUMMARY

Run No.	YD (g)	H_2O (g)	nBA (g)	MeOH (g)	Temp (°C)	Time (hr)	Observed Results
R1	3	1	1	-	75-80	1	a. Dark amber solution b. Upon cooling it solidified c. Residue dissolved in 25 ml MeOH
R2	2	-	5	-	85-90	2	a. Vigorous bubbling (NH_3 gas) b. Upon cooling did not solidify c. Mixture dissolved in 25 ml MeOH
R3	5	2.5	2.5	-	90	1	a. Dark amber solution b. Upon cooling it solidified c. Residue dissolved in 25 ml MeOH
K1	20	10	10	20	70-72	1	a. Dark amber solution b. Air dried to a solid residue
K2	20	10	10	20	75	2	a. Dark amber solution b. Air dried to a solid residue
K0.5	20	10	10	20	72	0.5	a. Dark amber solution b. Air dried to a solid residue
K3	20	10	10	20	73	3	a. Dark amber solution b. Air dried to a solid residue
K7.5	20	10	10	20	73	7.5	a. Dark amber solution b. No solidification overnight c. Viscous syrup residue
K27	4	-	4	4	74	27	a. Dark amber solution b. Upon cooling did not solidify
K10	20	10	10	20	74	10	a. Dark amber solution b. Upon cooling did not solidify
16	10	-	60	-	90	2	a. Dark syrupy liquid b. Air dried 1 week, stayed liquid
X1	5	2.5	2.5	-	90	1	a. Dark amber solution b. Air dried to dark brown solid with rectangular crystals c. Dissolved in 25 ml MeOH

The suspension method using the gelling agent, hydroxyethylcellulose to prevent precipitation of Yellow D, appeared promising initially. But it, only slowed the recrystallization process, and the explosive eventually plated out.

The sodium sulfide reduction and the acid/metal reduction procedures both gave satisfactory results as to the products obtained. However, both methods exhibited a process side effect which discouraged further studies. The strong base reduction using sodium sulfide would have introduced sulfur pollutants into the product and the combustion effluent. Although the acid concentration would not be excessively high in the reaction solution, the acid/metal reduction would produce too caustic an environment for the process equipment and would require an additional neutralization process.

The catalytic reduction of Yellow D using the palladium/carbon catalyst worked well in a Parr hydrogenator. Palladium was chosen as the catalyst for the hydrogenation because of its recyclability without the expense of a costly reactivation process. However, palladium recovery would be costly and time consuming. Thus, although the process had the other desired qualities, the additional recovery step discouraged further investigation.

The solvation study produced encouraging results which led to a more detailed study of the solvation/conversion reaction. Two solvents, dimethylsulfoxide and n-butylamine were selected from the three classes of organic solvents tested, and were proven useful in solubilizing the Yellow D/water slurry. Dimethyl sulfoxide, as with sodium sulfide used in the strong base reduction, would introduce sulfur into the process system and was rejected for that reason.

The second solvent, n-butylamine, exhibited an excellent solvation characteristic which was enhanced even further by the addition of methanol. When one part of Yellow D was dissolved in an equal part of

n-butylamine, the initial product was a fluid which gradually darkened as it aged. Evaporation of the volatiles produced a viscous mixture of crystalline solids and dark brown liquid.

Reaction of Yellow D with n-butylamine occured in two stages. The first stage was an amine exchange, which occurred rapidly as evidenced by the prompt evolution of ammonia gas (NH_3). This lasted for 10 to 20 minutes and was accompanied by an exothermic(10°C) rise in temperature of the reaction mixture. The product of the first stage was the N-n-butylammonium picrate salt.

The rate of the first stage reaction was measured by gas chromatography. Samples were taken out of the reaction mixture after 15 minutes, 30 minutes, 60 minutes and 120 minutes and refrigerated The samples were each extracted with 10% aq. HCl to bind up the ammonia and amine as aqueous salts and prevent any loss from the solution. The 15-minute sample contained only 17% of the original amount of ammonia held by the Yellow D, while no ammonia at all was left in the 30-minute, 60-minute and 120-minute samples. Thus, the ammonia was 83% expelled after 15 minutes of reaction, and completely replaced by butylamine within 30 minutes.

The second stage of the reaction was the gradual degradation of N-n-butylammonium picrate in the presence of water, methanol and excess butylamine into a complex mixture of many products. Of several types of structures that might be expected in the mixture, experimental evidence for a few of them has been noted, such as picric acid, dinitrophenol, etranitrophenol, quinones, anilines, and ring cleavage products.

The presence of the picric acid moiety remains strong, because stage-2 of the reaction does not deplete the concentration of the picrate portion of the mixture very rapidly. However, the many degradation products that account for the portion that does decompose, contribute to solubilizaion of the product.

An analytical study was conducted to detect evidence of similarity or difference between the compositions of products derived from Yellow D under variation of reaction temperature, time, concentration and reactant ratios. The initial differences that were detected largely disappeared as the product mixtures aged. The details of this study are given in the section on analytical work.

ENGINEERING EFFORT

Introduction

The laboratory tests previously discussed indicated that the proposed solvation/conversion process was a viable procedure for alleviating the problem of solidification and plating-out of Yellow D at WADF. A project was then outlined to conduct the process on a larger scale outside of laboratory conditions. A two-phase pilot plant program followed. The first phase had a 25-pound Yellow D process capacity. The second phase was a scaled-up version with a 65-pound capacity modified to incorporate improvements from the first-phase study. Both phases were carried out at the chemical reasearch facilities of the Ammunition Equipment Directorate, Tooele Army Depot, Utah during the period of September 1981 to June 1982.

Phase I Pilot Plant Study

Description of Process Equipment

The reaction/mixing tank was cylindrical and had a 38-gallon capacity. It was steam jacketed, with a cone-shaped bottom and a bolted lid equipped with a hinged access port. The tank was also equipped with a mechanical stirring apparatus and a dewatering fixture.

The dewatering storage tank was cylindrical and had a 38-gallon capacity. It was 23 inches in diameter and 23 inches tall, with a cone-shaped bottom, and was fabricated from 18-gauge 316-stainless steel.

The product storage tank was cylindrical and had a 64-gallon capacity. It was 23 inches in diameter and 36 inches tall, with a cone-shaped bottom and a hinged lid, and was fabricated from 18-gauge 316-stainless steel.

The hot water tank was cylindrical, and had a 64-gallon capacity. It was 23 inches in diameter and 36 inches tall, with a cone-shaped bottom and a hinged lid, and was fabricated from 18-gauge 316-stainless steel. It had two 10-kw immersion heaters in the bottom.

All pumps which came in contact with the solution were air-driven Sandpiper 1-inch STI-A stainless steel units of zero to 30-gpm capacity, with Teflon diaphrams and check valves.

The hot water pump was centrifugal, and driven by a 240-volt motor.

The heat exchanger had a cast-iron shell enclosing 0.25-inch copper tubes with 7.4 ft^2 of heat exchange area.

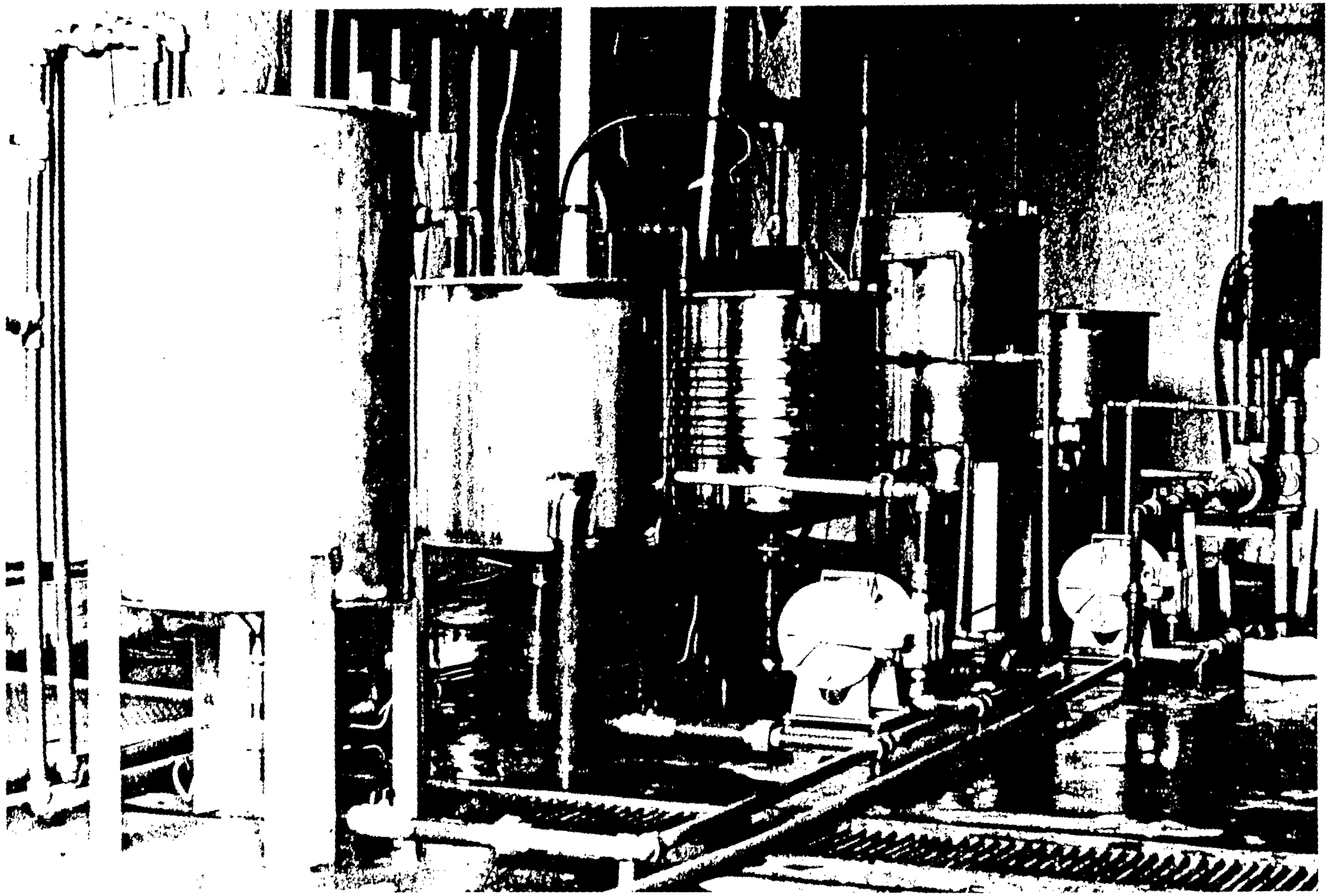
All piping and valves were polyvinylchoride (PVC).

Figure 8 illustrates the layout of the Phase I Pilot Process Equipment.

Operation Procedure: Phase I Pilot Plant

Hot water was pumped into the mixing tank, followed by Yellow D introduced through a top port. The mixture was heated and stirred at 45°C (113°F) and then allowed to cool and settle. Excess water was removed through plastic tubing with the dewatering pump. *n*-Butylamine was added and the mixture was reacted with agitation at 60°C (140°C) until total dissolution of the solid was attained. Methanol was added and the mixture made homogeneous by agitation. The mixture was pumped into storage and later introduced into burner for disposal by combustion.

The water (20 gal) for the mixing tank was heated in the dewatering storage tank to 54°C (129°F) by a heat exchanger before introduction into them mixing tank. A separate source of boiling water fed the primary side of the heat exchanger. The Yellow D was weighed in a plastic bag and added to the hot water in the mixing tank. The agitator for this mixture was operated by an air-driven motor. Heat was supplied to the jacket of the mixing tank by the circulation of boiling water. The butylamine and methanol were weighed by siphoning them separately into a preweighed plastic bottle which was then weighed again and emptied into the top port of the mixing tank. Phase I Pilot Plant Process Flow Chart is given in Figure 9.



PROCESS EQUIPMENT LAYOUT, PILOT PLANT-1

FIGURE 8

Phase II Pilot Plant Study, 65-pound Capacity

Description of Process Equipment

The mixing tank was a 42-gallon jacketed unit with a fiberglass glove box for its top. The tank and the bottom of the glove box (except for the open part over the tank) were made of 316-stainless steel. This system prevented Yellow D powder from contacting the operators and the area outside the glove box. A filtered suction line kept the glove box and tank at a slightly negative pressure. An agitator was powered by an air-driven motor.

The dewatering storage tank was made of 316-stainless steel and had a 38-gallon capacity.

The reactor was a cylindrical tank with a tapered bottom-extension for small batch processing. The tapered extension had a 3.4 gallon capacity and the whole tank had a 67.7-gallon capacity. The reactor was steam jacketed to provide heat for reaction. The bolted lid had a cold water jacket to condense the vapor (other than ammonia) produced during the reaction. Four vertically spaced thermocouples provided a temperature profile of the reactor during the reaction. Only 304- and 316-stainless steel were used to fabricate the tank.

The piping was 2-inch and 1.25-inch 316-stainless steel.

The product transfer pumps were Sandpiper air-driven diaphragm MPE pumps made of 316-stainless steel, with Teflon diaphragms and valves.

The metering pumps were made of stainless steel with Teflon seals and carbon cylinder sleeves.

The ball valves were manufactured of 316-stainless steel, with teflon seals, and pneumatically actuated.

The thermocouples were type T, copper-constantan encased in 316-stainless steel.

There were two sight glasses in the system, one in the dewatering loop and one in the exit pipe from the reaction tank. They were made of Pyrex and 316-stainless steel with Teflon gaskets.

All pilot plant components stood in a 304-stainless steel drip pan to contain spills.

A remote control room was provided with closed circuit television, monitoring of all process areas. All three tanks were provided with thermocouples, which were monitored by a multipoint chart recorder. The steam jackets were controlled by a Honeywell dial pack attached to thermocouples and monitored in the control room.

A list of process equipment and capacities is given in Table 13. Specifications and literature for some of the process equipment is given in Appendix O, AED Report 23-82.

TABLE 13

Phase II Pilot Plant
Process Equipment

Tank sizes-	Reactor.................65 gal
	Mixer...................38 gal
	Dewatering tank.........38 gal
Pipe sizes-	Mixer to reactor........2-inch piping
	Reactor to storage......2-inch piping
	All others..............1.25-inch tubing
Pumps-	Maximum flow............30 gpm
	Average flow, 30 psi....12 gpm
	Air supply..............40 psi
Average flow rates-	Water tank to mixer.....15 gpm
	Mixer to reactor.........9 gpm
	Dewater rate............0.13 gpm
Average heat transfer rate-	Steam to reactor........80 BTU/hrft° F
	Steam to mixer..........65 BTU/hrft° F

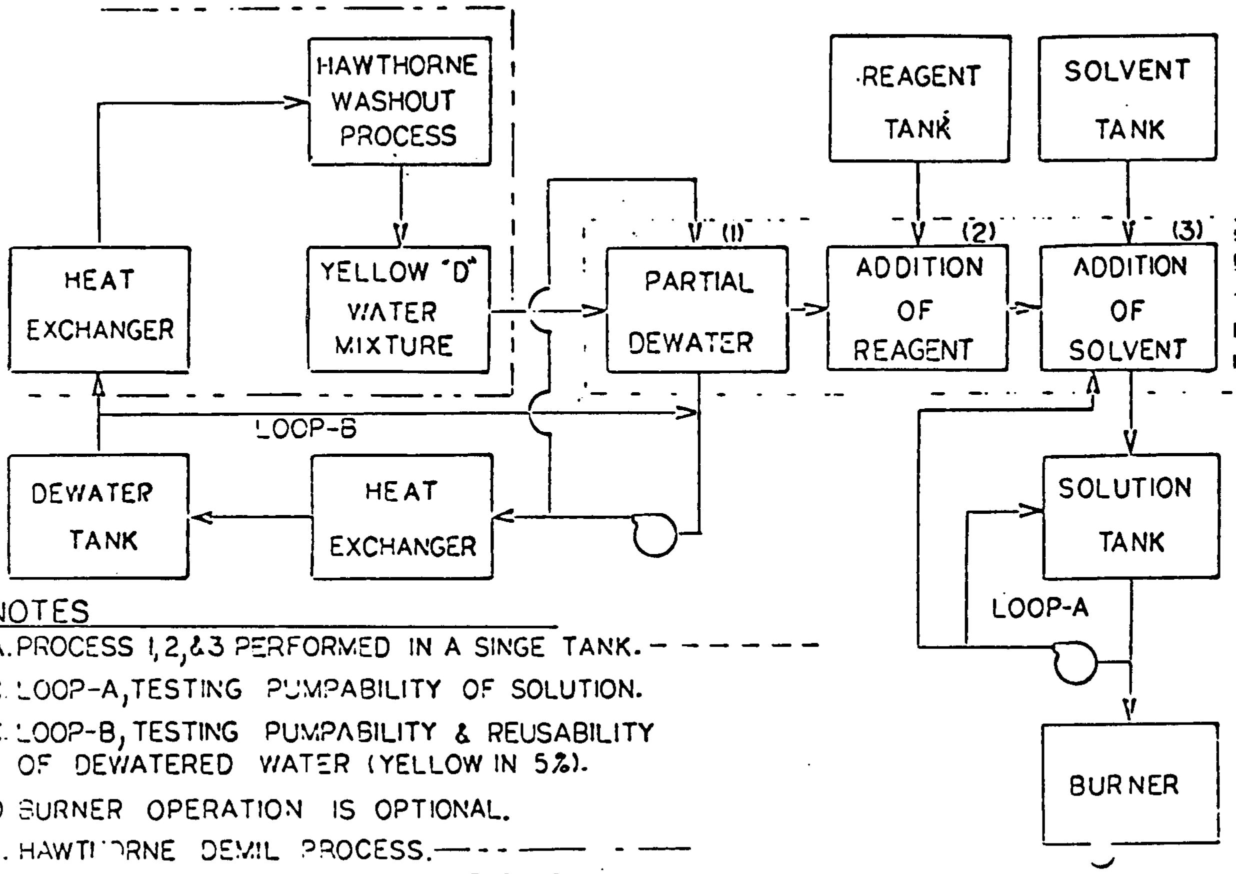
Operation Procedure, Phase II

Water was premeasured by a marked sight glass in the dewatering storage tank, and pumped into the mixing tank. Refer to Figure 10 for the illustration of the Phase II Pilot Plant, and the Figure 11 for the isometric process equipment layout. The water temperature was raised to 38°C (100°F) in the mixing tank. Yellow D in a plastic bag was removed from its cardboard shipping box, weighed and placed inside the glove box on the mixing tank. The glove box was sealed, the bag was opened with rubber gloves and the Yellow D was added to the hot water. The Yellow D and water were stirred continually and heated to 60°C (140°F) by circulation of steam through the jacket of the mixing tank. After 15 minutes the slurry was pumped into the reactor.

The amount of excess water in the slurry was determined and any excess water was distilled out by introduction of steam through the jacket of the reactor. The excess water was collected in the storage tank until the correct amount was removed from the slurry.

The pre-determined amount of n-butylamine was pumped into the chemical holding tank by metering pumps. The volume was checked by marks on the sight glass. The n-butylamine was then allowed to flow in to the reaction tank by gravity and mixed with the Yellow D/water slurry. The mixture was heated to complete the reaction under the conditions given in Table 14. The desired reaction time and temperature were controlled from the remote control room.

Upon completion of the reaction, a measured amount of methanol was metered into the chemical holding tank, and gravity fed into the reaction tank, where it was mixed thoroughly with the reacted material. The methanol served as a supplemental solvation and combustion medium. The product was then pumped into a marked storage vessel to await disposal. See Figure 12 for the Phase II Pilot Plant Process Flow Chart.



NOTES

A. PROCESS 1,2,&3 PERFORMED IN A SINGE TANK.

B. LOOP-A, TESTING PUMPABILITY OF SOLUTION.

C. LOOP-B, TESTING PUMPABILITY & REUSABILITY OF DEWATERED WATER (YELLOW IN 5%).

D. BURNER OPERATION IS OPTIONAL.

E. HAWTHORNE DEMIL PROCESS.

F. OPERATIONS 1-3 ARE MANUALLY PERFORMED

PROCESS FLOW CHART FOR YELLOW "D" EXPLOSIVE

PHASE I PILOT PLANT STUDY

FIGURE 9

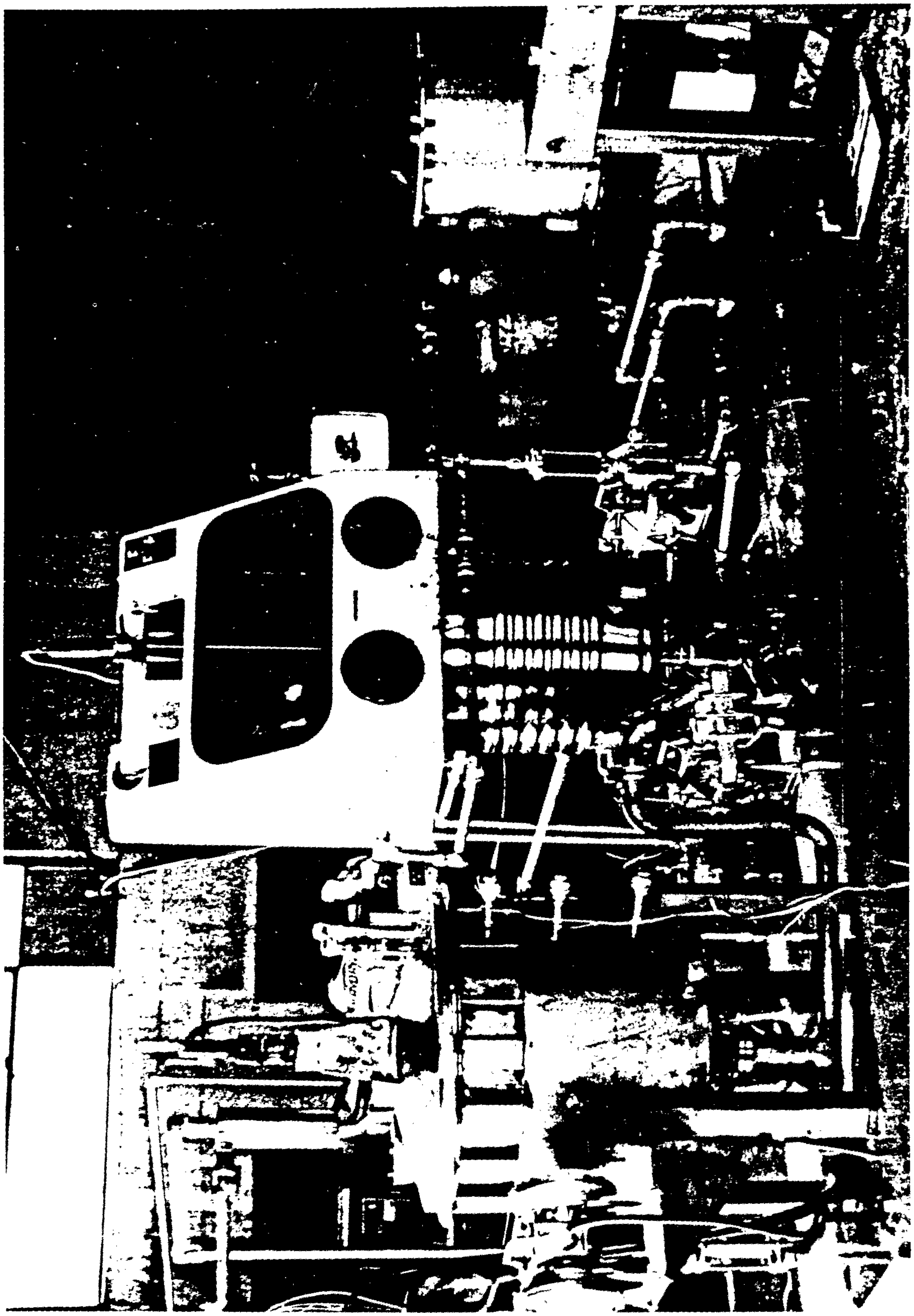
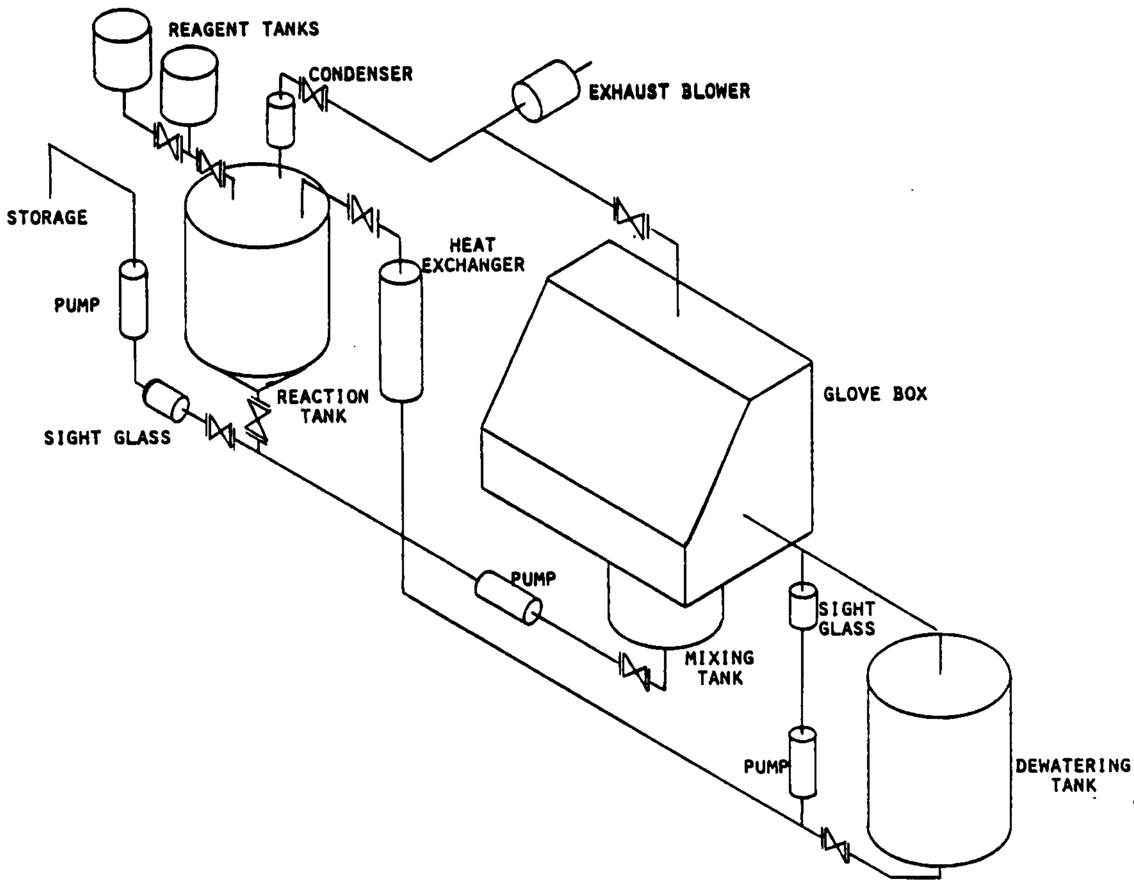
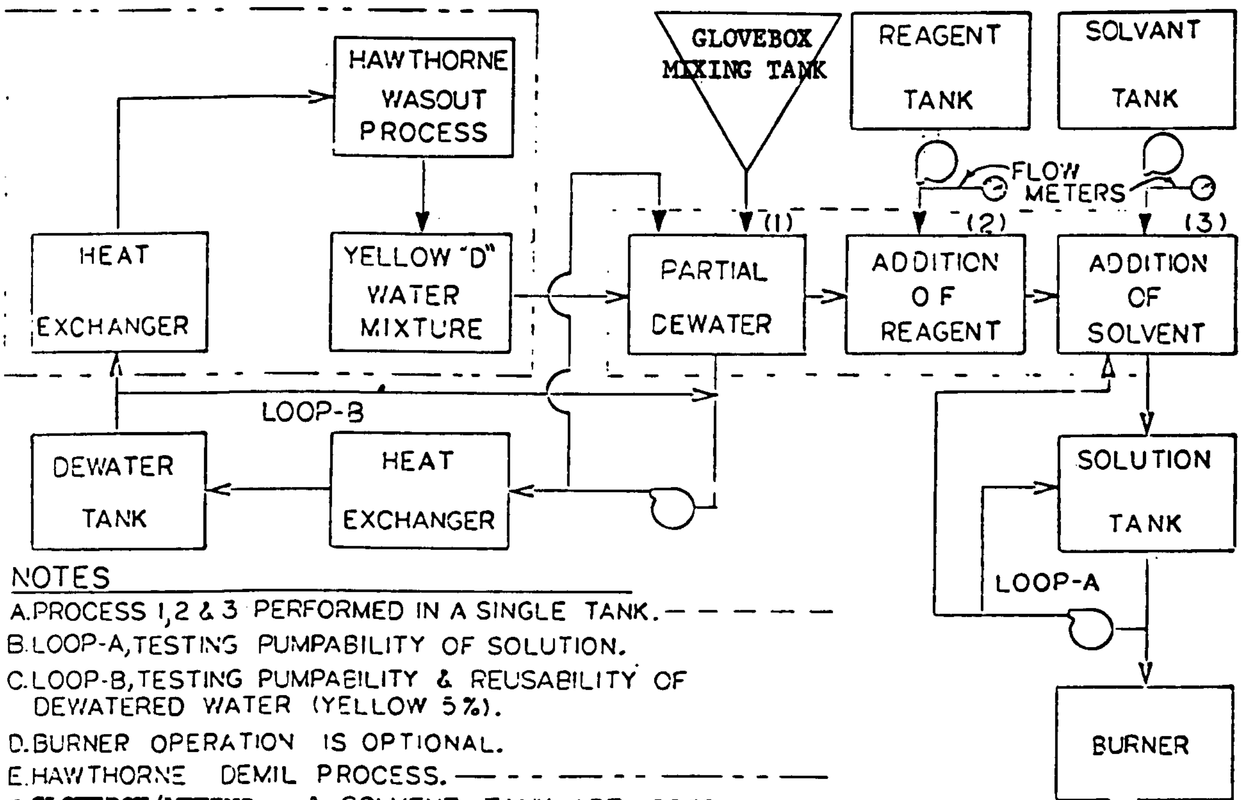


FIGURE 10



ISOMETRIC DRAWING
65-POUND PILOT PLANT

FIGURE 11



NOTES

A. PROCESS 1, 2 & 3 PERFORMED IN A SINGLE TANK. — — — — —
B. LOOP-A, TESTING PUMPABILITY OF SOLUTION.
C. LOOP-B, TESTING PUMPABILITY & REUSABILITY OF DEWATERED WATER (YELLOW 5%).
D. BURNER OPERATION IS OPTIONAL.
E. HAWTHORNE DEMIL PROCESS. — - - — - - — - - —
F. GLOVEBOX/MIXING & SOLVENT TANK ARE ADDED TO ELIMINATE OPERATOR EXPOSURE TO CHEMICALS.

PROCESS FLOW CHART FOR YELLOW 'D' EXPLOSIVE

PHASE II PILOT PLANT

FIGURE 12

TABLE 14

SUMMARY OF PILOT PLANT PHASE II YELLOW D/n-BUTYLAMINE REACTIONS

DATE	TEST NO.	LBS YD	QTY RATIOS BY WEIGHT WATER	nBA	MeOH	REACTION TIME/TEMP °C	UNIQUE PARAMETERS	COMMENTS
7/29/81	1	5	-	0.7	-		WATER syphoned off	
7/30/81	2	10	-	0.65	-	15/21	YD dissolved in water, cooled syphoned off	
8/7/81	3	30	0.8	0.5	1.25	72/21, 1/18-54	25 lbs MeOH added after 10 lbs of solution off	
8/11/81	4	40	0.6	0.5	1.0	2/30-52		
8/27/81	5	50	0.6	0.5	1.0	2.7/32-60		
8/28/81	6	50	0.6	0.5	1.0	3/20-63, 72/20		
9/12/81	7	49	0.3	0.3	0.5	0.5/38-71		
9/12/81	8	56	0.9	0.9	0.9	1/46, 0.5/52-71		
9/18/81	9	43	0.3	0.3	1.0	1/27-80		
9/18/81	10	60	0.5	0.3	1.0	-		
9/22/81	11	60	0.5	0.3	1.0	-		
4/23/82	1	12	1.0	1.0	1.0	0.5/20-54		
4/26/82	2	9	1.0	1.0	1.0	1/21-60		
4/27/82	3	9	2.1	1.0	1.0	1/21-75		
4/28/82	4	44	0.7	-	2.5	1/20-75, 20/20	hold over night	
5/19/82	5	29	1.2	1.0	1.0	2/20-80		
6/14/82	6	60	0	1.0	0.3	3.5/20-75, 7.0/20		
6/15/82	7	56	1.0	1.0	2.0	-		test aborted due to contamination
6/15/82	8	54	1.0	1.0	2.0	17/70		
6/16/82	9	55	0.75	1.0	2.0	0.75/70, 19/20-70		
6/22/82	10	53	0.25	1.0	2.0	3.5/70, 19/70-20		
6/24/82	11	54	-	1.0	2.0	3.5/70, 20/70-20		
6/28/82	12	52	0.5	1.0	2.0	3.5/70, 18/20	YD/water left over night, heat exchanger leak	
6/30/82	13	54	0.5	1.0	2.0	1/70, 42/20		approx 4 gal nBA added
7/2/82	14	56	0.5	1.0	1.8	0.5/32	short reaction time	
7/6/82	15	54	0.5	1.0	2.0	3.5/75, 31/20	hight temp reaction	
7/7/82	16	56	0.5	1.0	2.0	0.5/65, 18/20	MeOH added immediately	
7/8/82	17	55	0.5	1.0	2.0	19/20, 0.5/38	ambient reaction, over night	
7/10/82	18	53	0.5	1.0	2.0	3.5/65, 41/20		* 6 gal sample out after over night

Discussion of Results

Pilot plant studies conducted by AED showed that Yellow D/water slurry, reacted with n-butylamine and diluted with methanol, gave a product that could be burned in a furnace as fuel. Thus the use of fossil fuel for the disposal of Yellow D was eliminated.

The first stage of chemical reaction was the expulsion of ammonia from Yellow D with n-butylamine. This step was conducted with water present, but without methanol, which was not added until after the initial heating period of three hours at 65°C. This was followed by the slow degradation of the picrate moiety at ambient storage temperatures.

The weight ratios of reactants were 2:1:2:4 for Yellow-D/water/n-butylamine/methanol. Variations from the process conditions were tested in order to determine whether any dangers or difficulties would result from slight deviations or unintentional changes during production.

No problem is expected with an increase or slight decrease in the amount of butylamine from the recommended three-fold molar excess. However, the butylamine is also a solubilization factor, and cannot be decreased too much without leaving undissolved explosive.

The allowable decrease of amine should be determined. If water is not present at the start, the initial exotherm is very strong, which could cause (1) an uncontrolled temperature surge, (2) expulsion of some reaction mixture into the vapor exit line because of the rapid ammonia evolution, and (3) uncontrollable stirring mechanics. If too much water is present at the start, the n-butylamine will not dissolve the entire mixture. With a moderate excess of water during the heated period, two liquid layers are present, without solid. This is no problem during the reaction period if the mixture is kept warm and stirred. Changes from the prescribed initial amount of water do not lead to any danger or

handling problems if two conditions are satisfied: (1) The methanol is added within three hours after the end of the heated period, and (2) the amount of water is not less than half nor more than twice the prescribed amount.

The methanol increases fluidity, ensures that the components all stay in solution, and improves the burning behavior of the product. A delay of several hours at ambient temperature before the additon of methanol can result in a viscosity increase of the reaction mixture, with possible damage to the agitator, and a long delay before the solid can be redissolved and pumped out. No difficulty results from addition of the methanol along with the amine, or immediately thereafter at the start of the reaction, rather than at the end of the heating period.

An increase in the prescribed amount of methanol causes no handling or safety problem, but the use of only half as much methanol can upset the smooth flow of fuel into the burner. It is possible that the amounts of methanol and n-butylamine can be decreased in a final setup but the amount will have to be determined with the full scale equipment and final burner feed system.

The temperature of the stage-1 reaction can be increased about 10°C over prescribed temperature, but above that, too much n-butylamine is lost as vapor. A decrease in the reaction temperature has the same effect as shortening or eliminating the heating period. No serious difficulty has been observed from elimination of the heating period, or from heating the mixture longer than three hours. Heating ensures prompt removal of the ammonia and accelerates the stage-2 degradation. However, if the heating period is eliminated and other factors are also changed, which in themselves cause no problem alone, the combined effect could lead to problems, such as the formation of solids in the mixture. Before a decreased heating period can be recommended, the burning characteristics of the resulting product should be investigated.

Yellow D recovered from munitions by the hot water washout process contains a small amount (<0.5%) of insoluable residue, composed of asphaltic tar, magnetic powder, and metal (see analytical section). Most of this residue is separated by decantation of the product. A line filter separates the remaining residue.

A process review and evaluation conducted by Dr. M.J. Matsuguma, ARRADCOM, concurred that the overall solvation/conversion process was a viable and safe disposal method for the Yellow D/water slurry (see Appendix E, AED Report 23-82).

Additional information relating to pilot plant studies Phase I and Phase II are listed below:

<u>Phase I Pilot Plant</u>

1. The proposed conversion process was shown to have reasonable handling requirements.
2. A homogeneous liquid product was produced.
3. It was shown that the product could be burned.

<u>Phase II Pilot Plant</u>

1. The maximum batch size was scaled up to 65 pounds of Yellow D.
2. A detailed engineering-level handling procedure was established.
3. Process conditions were improved successively, to establish ranges of safe variations and to optimize some of the conditions within those ranges.
4. Toxicology and sensitivity tests were conducted on the product; no hazards greater than those of the initial components were detected.
5. The preliminary layout for a possible full scale up at WADF was planned, and the pre-design engineering parameters were calculated.
6. It was confirmed that the product could be burned continuously within environmental requirements.

ENGINEERING PARAMETERS

Introduction

The experimental work and the pilot plant effort provide the basis upon which the engineering parameters are derived. The actual parameter values are limited by the essential features of the process. The Explosive D solvation/conversion process gives good results when the weight ratios of Explosive D, water, n-butylamine and methanol are 2:1:2:4, and the handling procedure fits the following time and temperature protocol.

> Explosive D and water are reacted at 158°F with n-butylamine, which is fed into the mixture gradually over a period of 20 minutes. The rapidly evolved ammonia is allowed to exit through a water-cooled condenser, while the n-butylamine is retained. The condensed liquid n-butylamine flows back to the reactor. During this period of ammonia evolution the exothermic heat may have to be controlled by jacket cooling, after which the jacket will have to be heated again to maintain 158°F for another one to three hours with stirring. The mixture is cooled to 140°F and then the methanol is introduced as the mixture continues to cool to ambient temperature. The product is pumped to storage and allowed to age at least overnight before it is burned.

As seen below, part of this protocol will require careful adaptation in the scaled-up equipment.

Maximum Washout Rate

On-site inspection by AED personnel, and conferences with WADF personnel, provided details concerning potential Explosive D washout production rate. See Appendix K, AED Report 23-82, for explosive handling quantity and safety distance criteria.

Two stations in the South Tower of the Washout Building provide for handling the different sizes of munitions. A single cavity vertical washout chamber, will process the 8" and 16" projectiles one at a time. Up to 15 items can be washed out per shift with a resultant washout rate of up to 2300 pounds of Explosive D. This station uses hot water at 200°F and 80 psi.

The second station is a multi-position turret, on which up to 8 items can be mounted simultaneously, and subjected to either a cold water jet at 10,000 psi or hot water at 200°F and 80 psi. This system can washout about 360 items up to 6" diameter, producing as much as 4700 pounds of Explosive D per shift.

Thus the Explosive D washout rate at maximum capacity is about 4700 pounds per shift, with only one washout station operating at a time.

Realistic Washout Rate

It is expected that the maximum rate will seldom be maintained over a significant duration, and that very likely only about 3200 pounds (two-thirds of the maximum capacity) per shift will be a practical ongoing high production rate. The four 300-gal reactors planned for the Explosive D solvation/conversion process will handle 3320 pounds by processing two batches each per shift. With one batch in each of the four reactors per shift, they will meet a one-third rate of 1660 pounds of Explosive D starting material. The FY83 workload on the listed agenda totals about 147,000 pounds, or approximately 500 pounds per day. (See Appendix J, AED Report 23-82).

Dewatering

An average Explosive D/water ratio of 1:7 is expected from the hot water washout method. If the process uses 23,240 pounds of hot water to washout 3,320 pounds of Explosive D, it would be necessary to remove 21,580 pounds of water from the slurry to produce an Explosive D/water ratio of 2:1.

the reactor gradually as the water is distilled out. Steam fed to the reactor jacket supplies heat for the distillation. Dewatering by distillation would require approximately 6,300 BTU of heat per pound of Explosive D processed. Of course, the slurry must be assayed first, to a calculation of the amount of slurry to be fed in, and the final volume of the dewatered batch.

Ammonia Evolution

During the reaction of <u>n</u>-butylamine and Explosive D/water slurry, a total of 230 pounds of ammonia gas would be evolved for every 3320 pounds of Explosive D processed. Ammonia could be recovered to produce aqueous ammonium sulfate fertilizer by neutralization with dilute sulfuric acid. It would require 3,304 pounds of 20% aqueous sulfuric acid to neutralize 230 pounds of ammonia. This would produce 3,534 pounds of 25% aqueous ammonium sulfate (fertilizer). The ammonia gas could also be used as a reducing agent in the explosive incinerator to reduce emissions of NO_x.

Major Process Equipment

The following equipment would be necessary for the proposed Explosive D processing at WADF.

1. Solvation/Conversion Reaction Kettles - Each reaction kettle should be constructed from 316-stainless steel and equipped with a stirring mechanism and two condensors. The capacity of the reactors should be about 300 gallons each, and four such reactors are needed. See Appendix 0, AED Report 23-82 . Production kettles equipped with jackets for steam heating and water cooling are the preferred type, similar to those used at the Hawthorne Ammunition Plant. As discussed in the dewatering process, the removal of excess water from the Explosive D slurry is also accomplished in the reaction kettles.

2. Reagent Holding Tanks - Two reagent tanks with a holding capacity of 200 gallons each would be located on the second floor of the washout building. Construction material would be 316-stainless steel.

3. Reagent Storage Tanks - Reagent storage tanks are necessary to store n-butylamine and methanol. These tanks should be constructed from 316-stainless steel, with a holding capacity of 36,000 gallons total for methanol and 30,000 gallons total for n-butylamine.

4. Product Storage Tanks - Product storage tanks, with a total capacity of 24,000 gal, will store the reaction product prior to burning. These tanks should be constructed from 316-stainless steel. They will be located near the incinerators.

5. Pumps - All pumps should be 316-stainless steel air actuated diaphragm pumps with Teflon diaphragms. The rating of each pump should be determined during the pre-design activities.

6. Condensors - Two condensors fabricated from 316-stainless steel, and preferably of shell and tube type construction are needed for each reactor. One is to condense the butylamine vapors and one is to condense the water vapor distilled from the slurry. The rating of these condensors should be determined during the pre-engineering consultations.

Engineering Calculations

The engineering calculations are tabulated into charts for easy utilization. They are provided to allow quick determination of several process parameters which match any chosen amount of Explosive D to be handled per batch. To use the charts, either the desired batch size (weight of Explosive D) or the desired reactor size is used as the base criterion, and the other factors are calculated from column 1 or column 2 respectively. (See Tables 15, 16, 17).

TABLE 15

ENGINEERING PARAMETERS

Item/Operation	TOTAL PRODUCTION (6 hours/shift)			BATCH TANK SIZE (TOTAL/8)		
	pound	gallon	SCF	pound	gallon	SCF
Explosive D/H2O slurry production/shift:						
a-Dry explosive D removed[1]	3,320					
b-Washout water[2]	23,240					
c-Total slurry produced[3]	26,560	3,000				
Dewatering:						
a-Water removed	21580	2,591		2,697	324	
b-BTU requirement	20,930,000			2,616,250		
c-Steam requirement @120 psi			10,028			1,250
NH3/H2SO4 neutralization System:						
a-NH3 production	232		4,901	29		613
b-H2SO4 requirement @93%	674					
@20%	3,304	300				
c-(NH4)2SO4 produced @dry	830					
@20% solution	3,534					
Major Equipment:						
a-reaction kettle @ 1-½:1:2 reactant ratio	14,720	1,920		1,840	240	
b-reagent holding tanks						
n-butylamine tank	3,320	67		415	8.4	
methyl alcohol tank	6,640	126		830	15.8	
c-reagent storage tanks @ 1 month supply						
n-butylamine tank		2X6,000				
MeOH tank		4X6,000				
d-product storage tanks @ 2 weeks supply		4X6,000				

Note: (1) assuming the actual production time of 6 hours per 8 hour shift.
(2) maximum calculated washout rate/ 4,800 pound per shift, the projected washout rate/3,320 pound.
(3) washout explosive D/water slurry ratio is assumed to be 1:7.

TABLE 16

COEFFICIENTS FOR CALCULATION OF REACTANT AMOUNTS AND TANK SIZES

	Coefficient per Pound YD	Coefficient per Gal Capacity	Example 1	Example 2
Reactor Capacity	>0.7230 gal	1.000 gal	1000 gal	300 gal
Charge Maximum 80% of Capacity	<0.5780 gal	0.800 gal	800 gal	240 gal
Void Volume	>0.1445 gal	0.200 gal	200 gal	60 gal
YD Charge	1.000 p	1.384 p	1384 p	415 p
Water, 8.33 p/gal	0.5000 p	0.692 p	692 p	208 p
	0.0600 gal	0.0831 gal	83 gal	25 gal
n-Butylamine, 6.20 p/gal	1.000 p	1.384 p	1384 p	415 p
	0.1611 gal	0.223 gal	223 gal	67 gal
Methanol, 6.60 p/gal	2.000 p	2.768 p	2768 p	830 p
	0.3028 gal	0.419 gal	419 gal	126 gal
Ammonia Produced	0.0691 p	0.0956 p	96 p	29 p
YD Fuel Produced, 7.67 p/gal	4.431 p	6.132 p	6132 p	1840 p
	0.5780 gal	0.800 gal	800 gal	240 gal
Methanol Metering Tank	0.361 gal	0.5 gal	500 gal	150 gal
Methanol Storage Tanks for 1-Month Quota at 2 Batches per Day per Reactor	4x14.45 gal	4x20 gal	4x20,000 gal	4x6,000 gal
n-Butylamine Metering Tank	0.217 gal	0.3 gal	300 gal	90 gal
n-Butylamine Storage Tanks for 1-Month Quota at 2 Batches per Day per Reactor	7.23 gal	4x10 gal	4x10,000 gal	2x6,000 gal

TABLE 17

REACTOR SIZE BASED ON EXPLOSIVE PRODUCTION BATCH SIZES

YELLOW D - REACTOR SIZE BASED ON AMOUNTS OF REACTANTS

WASHOUT RATE/SHIFT	RESIDUAL WATER AFTER DEWATER	nBA	MeOH	TOTAL POUNDS	LIQUID VOLUME CUBIC FEET	LIQUID VOLUME GAL	DIAMETER OF REACTOR 80% FULL 6' HEIGHT	DIAMETER OF REACTOR 80% FULL 5' HEIGHT	DIAMETER OF REACTOR 80% FULL 4' HEIGHT
Pounds	Pounds	Pounds	Pounds				ft. in.	ft. in.	ft. in.
4,200	2,100	4,200	8,400	18,900	329	2,464	9 4	10 2	11 5
4,000	2,000	4,000	8,000	18,000	314	2,347	9 2	10 0	11 2
3,800	1,900	3,800	7,600	17,100	298	2,229	8 11	9 9	10 11
3,600	1,800	3,600	7,200	16,200	282	2,112	8 8	9 6	10 7
3,400	1,700	3,400	6,800	15,300	267	1,995	8 5	9 3	10 4
3,200	1,600	3,200	6,400	14,400	251	1,877	8 2	8 11	10 0
3,000	1,500	3,000	6,000	13,500	235	1,760	7 11	8 8	9 8
2,800	1,400	2,800	5,600	12,600	220	1,643	7 8	8 4	9 4
2,600	1,300	2,600	5,200	11,700	204	1,525	7 4	8 1	9 0
2,400	1,200	2,400	4,800	10,800	188	1,408	7 1	7 9	8 8
2,200	1,100	2,200	4,400	9,900	173	1,291	6 9	7 5	8 3
2,000	1,000	2,000	4,000	9,000	157	1,173	6 5	7 1	7 11
1,800	900	1,800	3,600	8,100	141	1,056	6 1	6 8	7 6
1,600	800	1,600	3,200	7,200	126	939	5 9	6 4	7 1
1,400	700	1,400	2,800	6,300	110	821	5 5	5 11	6 7
1,200	600	1,200	2,400	5,400	94	704	5 0	5 6	6 1
1,000	500	1,000	2,000	4,500	78	587	4 7	5 0	5 7
800	400	800	1,600	3,600	63	469	4 1	4 6	5 0
600	300	600	1,200	2,700	47	352	3 6	3 10	4 4
400	200	400	800	1,800	31	235	2 11	3 2	3 6
200	100	200	400	900	16	117	2 0	2 3	2 6

NOTE:

1. The height of the reactor is limited to six feet or less, to stand lower than the slurry holding tank, so that the Explosive D and water mixture can flow from the holding tank to the reactor by gravity.

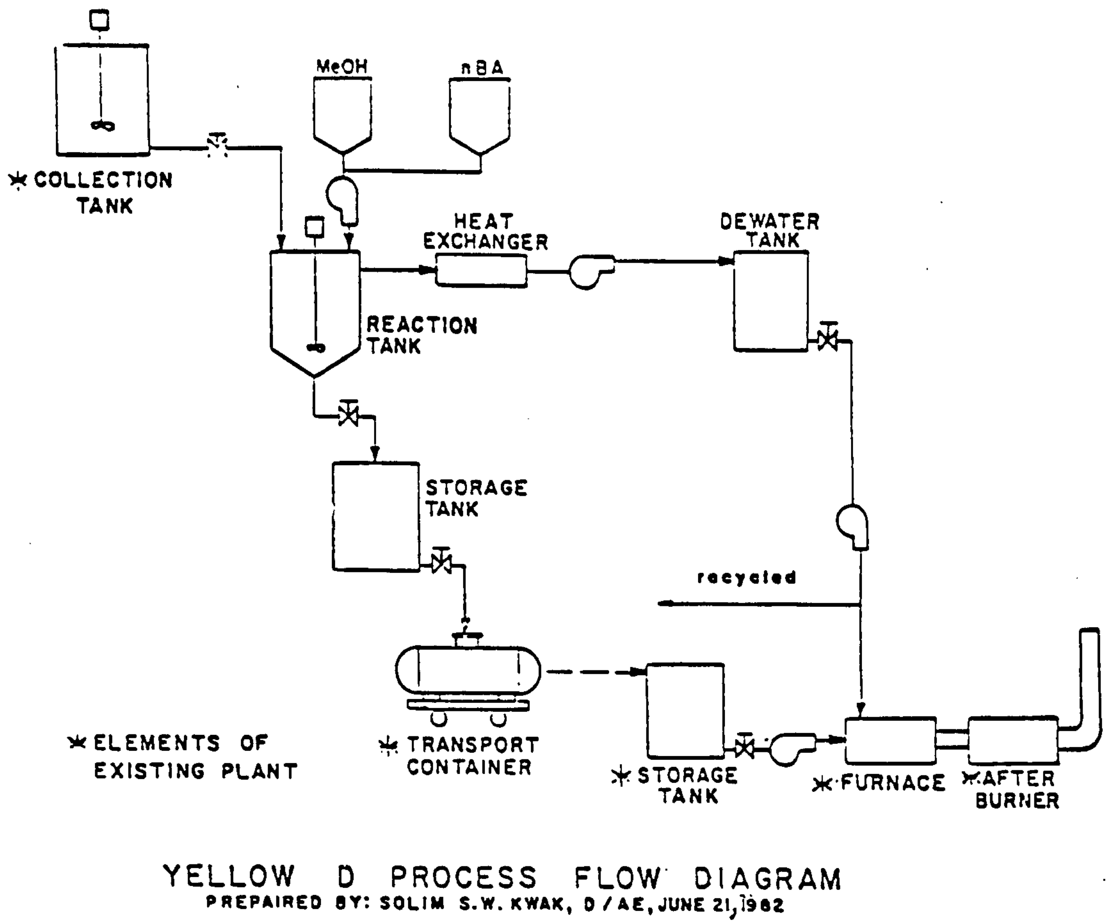
2. The Explosive D/water ratio after dewatering is 2:1.

3. The density of the Explosive D/water/nBA/MeOH mixture is 0.92 g/ml (7.67 lb/gal).

4. The above chart gives reactor size for a void volume of 20%.

Flow Chart and Equipment Layout

A simplified process flow diagram and the equipment layout are shown in Figure 13 to help visualize the installation of process equipment and to aid the subsequent engineering activities.



EXPLOSIVE D SOLVATION/CONVERSION PROCESS

FLOW DIAGRAM

FIGURE 13

BURN TEST

Introduction

One of the objectives of the project was to determine the feasibility of burning the Yellow D conversion product in a furnace as fuel in complaince with EPA. The tests were conducted in two burners; the first was a modified tent heater and the second was a Hauk high pressure oil burner.

Description of Burners

Herman Nelson Heater

The first burner was a converted Herman Nelson tent heater in which the standard gasoline powered engine was replaced by an electric motor. There were no controls for fine adjustment of the burner. This prevented the collection of data, but it did show that the Yellow D solution will burn. The converted Herman Nelson Heater is shown in Figure 14.

Hauk High Pressure Oil Burner

The tent heater was later replaced by a larger furnace designed and fabricated by AED. A schematic of the furnace is shown in Figure 15. The new design allowed for better control of the burning process and changes in the test parameters.

Burner. The burner is a Hauck 530 high-pressure oil burner. It is controlled by adjusting three parameters.

1. The air control registers.
2. The fuel pressure.
3. The atomizing air pressure.

Pump. The fuel pump is a diaphragm pump which utilizes a teflon diaphragm to insure inert behavior toward the reaction mixture.

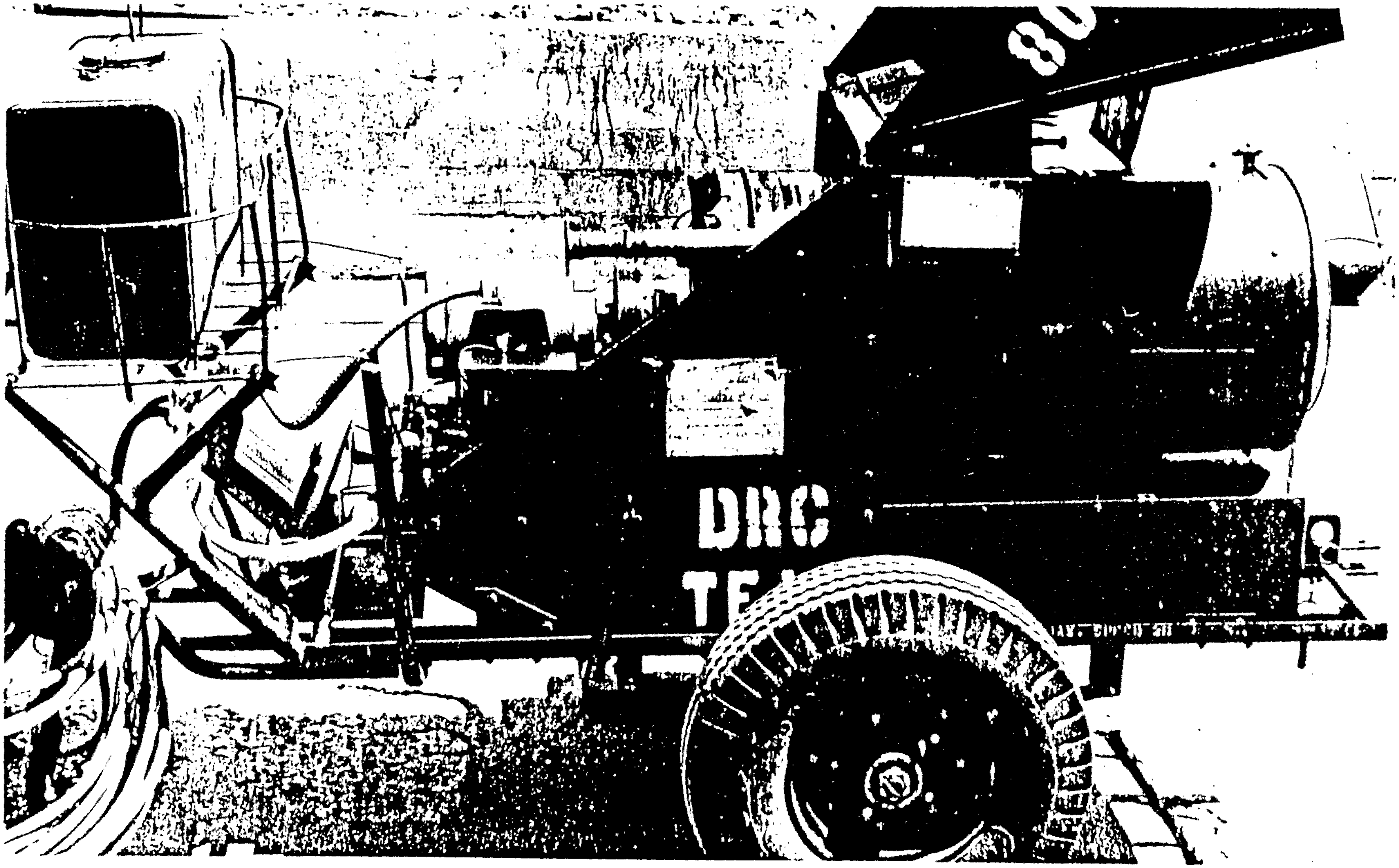
Pilot. The pilot is a Hauck 110A high pressure gas inspirator which uses propane as a fuel source. It serves as a pilot as well as a preheater to bring the furnace up to temperature before starting the main burner.

Refractory. The shell of this furnace consists of a 24" x 24" x 12" steel case filled with a castable refractory material similar to the A.P. Green Co. 2400°F grade. The burner is mounted on Hauck burner tiles cast into the main housing.

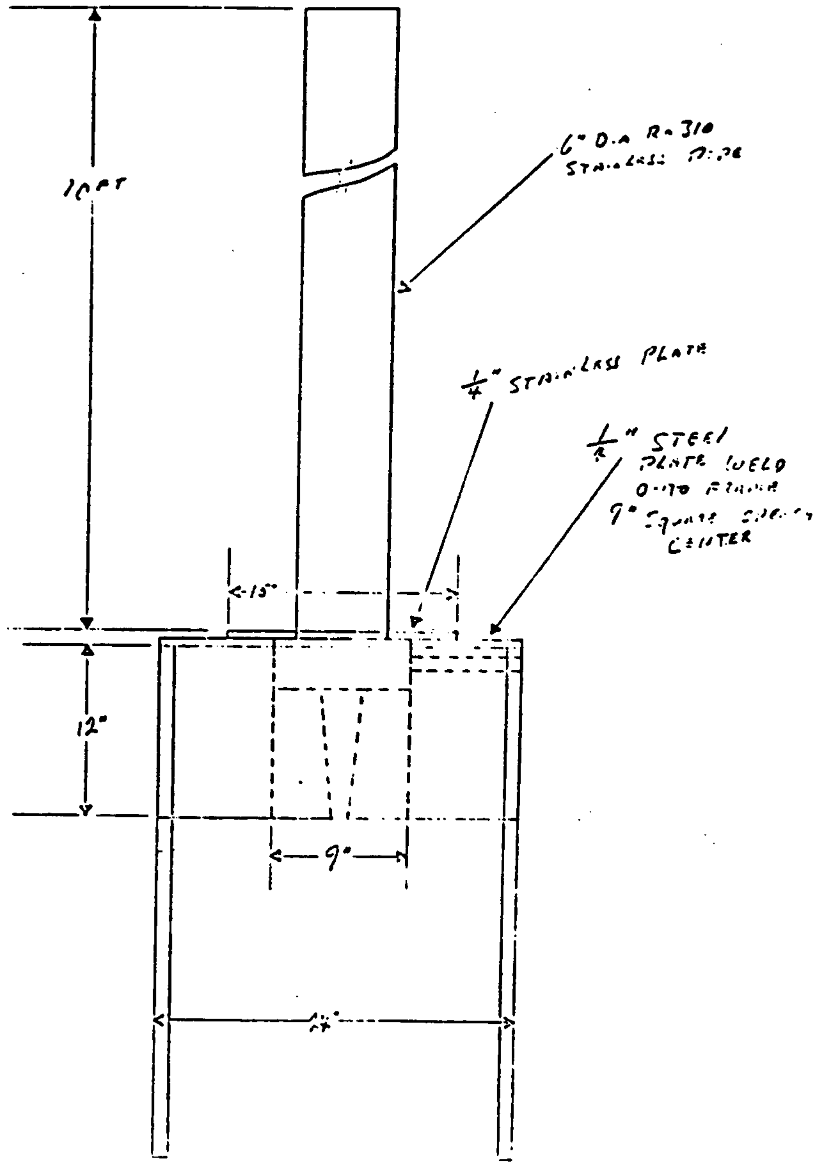
Burn Test Procedures

Phase I Burning Test (Yellow D Solution)

Solution Preparation. To prepare a solution of Yellow D for burning, a mixture was made composed of 340 grams of Yellow D, 150 grams of water, 180 grams of *n*-butylamine, and 300 grams of methanol. The components were added to the flask in the order listed above. Before adding the methanol, the flask was vigorously agitated to dissolve the Yellow D. Later, in the feed tank, the solution was diluted to about 18% by adding another quart of methanol.



CONVERTED HEQMAN NELSON HEATER



SCHEMATIC OF HAUK HIGH PRESSURE OIL BURNER

FIGURE 15

A second solution, used as straight burner fuel, was made from 600 grams of Yellow D, 200 grams of water, 600 grams of methanol methylalcohol, and 300 grams of n-butylamine. The concentration of Yellow D was approximately 18% for the second test.

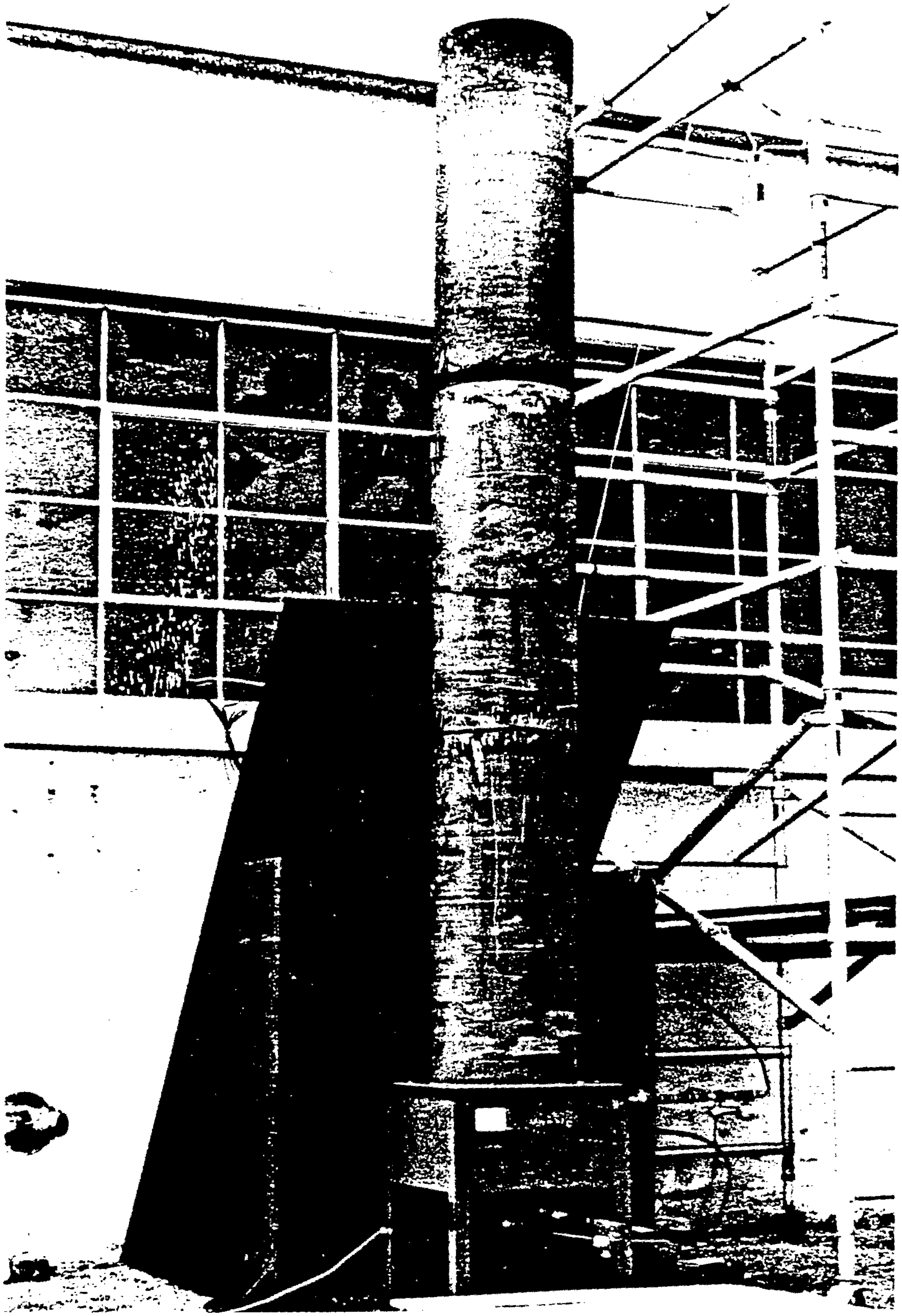
Burn Test Procedure. The Herman Nelson burner was set up outside the AED test site barricade, and started on methanol. A thermocouple and recorder were set up to detect burner activation. The fuel was then switched made from methanol to Yellow D solution. The Yellow D solution burned as expected with no complication. The solution tank was allowed to drain completely and then methanol feed was resumed to purge the burner system.

Phase II Burning Test (Conversion Product)

Five 5 gallons of the reacted Yellow D product was placed into a fuel storage container equipped with a fuel pump. The phase II burner system was installed on a concrete apron at the test site. See Figure 16 for the general layout of the burner system.

The burner was preheated with methanol. After the burner was stabilized, the reacted Yellow D product was introduced through the burner orifice as fuel. During the test, the propane pilot was kept burning to prevent build-up of the fuel in the burner in case the flame were to expire or the temperature were to drop low.

Upon completion of the burn tests, the fuel line was purged with metanol. When the purge was completed, the fuel and the air were



BURN TEST HAUCK HIGH PRESSURE OIL BURNER SET UP

FIGURE 16

turned off. The propane pilot was run for several minutes longer to ensure that no fuel remained in the burner. This purge was very important to avoid clogging of the burner head.

During these burn tests, gas samples were taken and analyzed (See Effluent Analysis), and Combustion temperatures were measured at various locations on the stack.

Monitored Parameters for Burn Test

The parameters monitored during the burn test were:

1. Fuel Flow
2. Atomizing
3. Fuel Pressure
4. Temperatures monitor locations:
   a. Burner
   b. Flame
   c. Two additional stack locations at 6" and 7' heights.

The temperature was monitored by four thermocouples which were attached to a multipoint chart recorder. See Appendix H, AED Report 23-82, for burn test details.

Reducing Properties of Yellow D Product And Ammonia

In unrelated projects we have considered the use of ammonia as a reductive supplement in the demil incineration processes to oppose formation of NO_x stack pollutants. Any reducing gas might be considered for this purpose. In the process for fuel production from Yellow D the above principle is applicable at two points.

Ammonia gas is emitted by the process as a side product and could best be disposed of by its use in any furncae operation to assist in meeting EPA requirements. Indeed, ammonia is actually a fuel with a heat

Ammonia gas is emitted by the process as a side product and could best be disposed of by its use in any furnace operation to assist in meeting EPA requirements. In fact, ammonia is actually a fuel with a heat of combustion of 9,600 BTU/pound. NO_x is formed from the N_2 in air, as in ordinary boilers and other types of burners. In addition there is excess NO_x from the nitro explosives themselves.

If the ammonia produced by this project is disposed of by acid neutralization, a useful fertilizer results. But the greater advantage is to use it on-site to accomplish EPA needs that must be provided for anyway, and to use its energy content simultaneously.

The principle of NO_x reduction also applies to the nature of the amino group of the Yellow D product. The solubilizing agent for Yellow D in this process is n-butylamine, which is also a fuel by virtue of the hydrocarbon group as well as the amino group. Both groups are also reducing agents and can contribute to the elimination of stack NO_x which originates both from decomposition of the explosive and from nitrogen gas in the air.

Thus it is expected to achieve low pollutant emission from combustion of Yellow D product by adjustment of air and fuel feed rates and other furnace parameters. The burn tests showed that the proper adjustments lowered NO_x and NO monitor readings from 500 ppm to less than 5 ppm. Additional adjustments should also allow complete oxidation of CO to CO_2, by manipulation of various factors such as air and fuel injection locations.

Discussion of Results

The two objectives, in both Burning Tests, Yellow D conversion products were used as fuel of EPA compatibility and retention of solubility, were achieved to the extent of demonstrating feasibility. The resulting fuel remained fluid and was easily pumped throughout the reaction system and into the burner. If the water content of the fuel was kept down to the level specified in the process, the fuel burned smoothly and continuously at proper feed rates, with the absence of smoke, NO_x, and NO. The effluent was clear and colorless. The carbon monoxide which resulted from these settings was down to 0.84%. No attempts were made to lower it further while maintaining negligible NO_x. The results of Burn Tests are summarized in Tables 18 and 19.

TABLE 18

CONVERTED YELLOW-D BURNING TEST RESULTS

RUN No.	Ext Press PSI	Line Press PSI	FLOW RATE Gal/Min		STACK TEMPERATURE °F				BURN TIME (min.)	FLUE OUTPUT	QUALITY OF BURN	COMMENTS
			FUEL	MeOH	4'	14'	7'	11 1/2'				
MeOH	35	1	0	0.12						Clear	Smooth	Preliminary set-up
MeOH	35	15	0	0.56						Clear	Smooth	"
MeOH	35	45	0	0						Clear	Smooth	"
3	35	45	unkwn	0								"
5	35	30	unkwn	0					5	Clear	Smooth	"
6	35	15	0.29	0					5	Clear	Smooth	"
6	35	45	0.19	0					5	Clear	Smooth	"
6	35	33	0.43	unkwn					8	Clear	Smooth	"
8	35	10	0.24	0					5	Clear	Smooth	"
Propane	0	0	0	0	1600	1580	1300	120				"
MeOH	32	1/2	0	0.1	1080	1140	1050	2000+	1 1/2			"
6	32	20	0.5	0.1	1760	1440	1300	130	2 1/2	Clear	Smooth	
6	32	15	0.5	0.13	1680	1440	1280	130	4	Clear	Smooth	
12	35	10	0.5	0.1	1500	1600	1350	1670	3	Clear	Rough	
12	35	15	0.5	0	1720	1600	1400	1300	5	Clear	Smooth	
8	35	25	0.5	0.1	1800	1360	1210	900	1	Slight smoke	Smooth	
8	35	15	0.1	0.13	1680	1300	1170	750	1	Clear	Smooth	

TABLE 19

CONVERTED YELLOW-D BURNING TEST RESULTS

RUN No.	Ext Press PSI	Line Press PSI	FLOW RATE Gal/Min		STACK TEMPERATURE °F				BURN TIME (min.)	FLUE OUTPUT	QUALITY OF BURN	COMMENTS
			FUEL	MeOH	4"	14"	7'	11 1/2'				
Propane	0	0			175	133	180	220	-	Clear	Smooth	Propane only
"	36	8		7/8*	1660	1750	1500	170	-	Clear	Smooth	Propane & MeOH
"	36	8		"	1750	1780	1530	180	-	Clear	Smooth	" "
4	36	6	3/4*	3/4*	1790	1500	1345	175	2	Slight smoke	OK	
12	36	15	"	5/8*	1830	1700	1450	350	5	Clear, flashes	Rough	Air in line.
18	36	15	Full*	"	1480	1640	1460	230	8			
"	36	20	"	0.13	1760	1800	1500	170			Smooth	Burner plugged; foreign object visible in fuel line.
12	36	25	3/4*	5/8*	1650	1590	1360	1420		Slight smoke, flashes	Smooth	
12	36	30	.5	.05	1570	1540	1310	270		Clear	Smooth	
12	36	30	.5	0	1710	1570	1335	180		Clear	Smooth	
12	36	32	.54	0	1490	1490	1290	140	60	Clear	"	
12	36	35	"	0	1430	1580	1390	1500		Clear, flashes	"	
12	36	30	"	0	1740	1600	1370	1380		Clear	"	
12	36	35	"	0	1580	1550	1340	1505		"	"	
10	36	36	"	0	200	1670	1630	1360		"	"	
10	36	24	"	0	144	1575	1325	1185	60	"	"	Smell
10	36	30	"	0	130	1570	1392	1217		Slight Smoke	"	Smell
10	36	26	"	0	150	1630	1416	1245		Clear	"	Slight smell
14	38	16	"	0	1510	1700	1360	1200	10	Slight smoke, sparks	"	Strong smell

* Indicates position of fuel or MeOH feed line valve. Flow rates not measured.

EFFLUENT ANALYSIS

Introduction

The products from the yellow D conversion process were burned in a furnace to determine the combustion characteristics (See Burn Test Section for details). During these burn tests, effluent analyses were conducted to monitor and determine the combustion by-products and their concentrations

Test Procedure

Samples of the gaseous effluent from the combustion of reaction products were taken during two separate on-site burn tests. In the first on-site test, gas reagent tubes were used to monitor common combustion products. Gaseous effluent samples were also taken in stainless steel gas sampling bottles and analyzed by mass spectrometry. During the second on-site test, the reagent tubes and mass spectrometric methods were again employed. In addition, an NO-NO_x continuous monitor was used to determine the concentration of NO and NO_2 throughout the tests

Stack Probe

A sample probe was inserted near the top of the burner stack. The location of the probe allowed sufficient mixing to give a representative effluent sample. Approximately 40 feet of copper and rigid polyethylene tubing connected the stack probe to the analytical workbench and sampling apparatus. During the second on-site test, a water trap was added to the system to collect the water condensing in the tubing.

Sampling Procedure

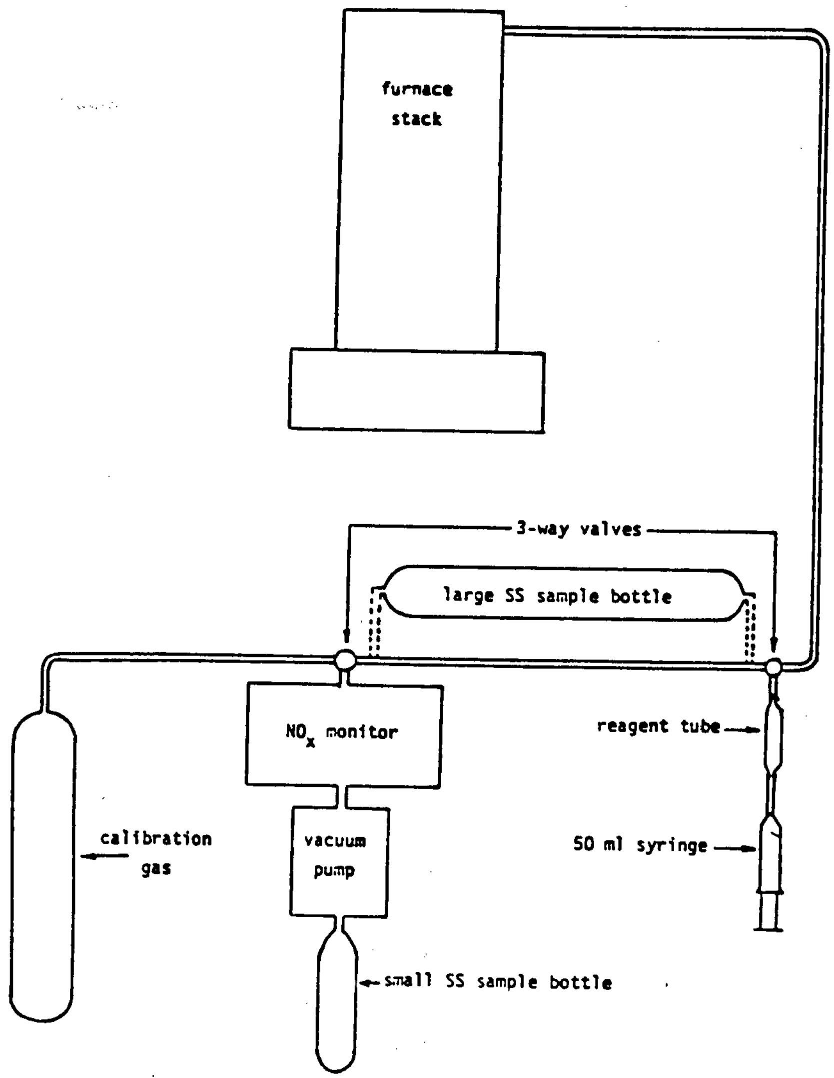
The tubing from the stack probe was connected to a vacuum pump so that stack effluent was continuously drawn through the tubing and was introduced into the NO analyzer. Reagent tube samples were taken by drawing a known amount of stack effluent through the desired reagent tube using a 50 ml syringe. A schematic diagram of the system is shown in Figure 17. Samples of mass spectrometric analysis wre taken in two ways. A large (1 gallon) stainless steel sample bottle was purged first with stack effluent for 5 to 10 minutes, and filled with the effluent gases. Smaller bottles (300 cm^3) were purged for 5 minutes and pressurized with stack effluent to 30-50 psi. The large bottle provided an ambient pressure sample with no possibility of contamination from the pump or filters.

Mass Spectrometric Analysis

The stack effluent samples in the stainless steel sample bottles were analyzed on a Hewlett-Packard 5980A quadruple mass spectrometer. The bottles were heated to above 100°C using heat-tape to ensure that all water was vaporized. The flow valve was opened to allow a small, constant flow of stack effluent to enter the mass spectrometer ionization chamber and mass analyzer. Ionization was accomplished by electron impact at 70 eV.

NO/NOx Monitor

A Thermo-Electron Series 10 NO-N$)_x$ monitor was added to the system during the second on-site test. The monitor was calibrated using a calibration gas which was 219 ppm NO in N_2 gas. It was then set to give full-scale deflection for a concentration of NO_x (i.e., NO + NO_2) of 1000 ppm. The detection limit at this range was 4-5 ppm.



SCHEMATIC DIAGRAM OF EFFLUENT ANALYSIS SETUP

FIGURE 17

Results and Discussion

Reagent tube analysis from test #1 indicated high concentrations of NO and NO_2. However, mass spectra showed almost no detectable concentrations of either NO or NO_2. These results seemed contradictory. The results of the second test, with the continuous NO_x monitor, in line, showed that the burn can be adjusted for minimum NO_x production. In the presence of a reducing amine (n-butylamine) the flame can be adjusted to the point where the major nitrogen-containing product of the combustion was nitrogen gas (N_2) with little or no oxides of nitrogen produced. However, the reagent tubes indicated that minimization of the NO_x produced a high concentration of carbon monoxide (CO). During the first effluent analysis the reagent tubes indicated CO in the percent range by volume. It was noted that CO concentrations taken during test #2 were in the ppm range rather than the percent range. The mass spectral samples which were taken during a later burn, were sampled while the flame was optimized for low NO_x production.

The mass spectra confirm the analysis of the effluent as containing primarily CO_2, CO, N_2, O_2, H_2O, and argon. The peak at m/e = 28 could be due to either N_2 or CO. The relative abundance ratio of m/e = 28 to m/e = 29 indicates a compound containing one carbon. For example, the abundances from Table II show a m/e 28:29 abundance ratio of 85:1, corresponding well to the natural isotopic ratio for C12 :C13 of 100:1.1. In addition, the mass spectrum of room air shows no peak at m/e = 29. Thus, the isotopic ratios indicated a substantial percentage of the m/e = 28 peak to be due to CO. The Mass spectral analysis also shows small peaks at m/e = 58 and m/e 43. These peaks are undoubtedly products of the combustion and very likely organic compounds, the identity of those compounds is uncertain.

The effluent analysis indicated that the Yellow D/n-butylamine reaction product can be burned efficiently, and the flame can be optimized for low NO_x production. However, CO production is at least 0.84% in all burns monitored thus far.

The summary of the results is given in Tables 27 through 31 and spectra of mass spectrometric analysis is shown in Figures 54 to 56. See the complete discussion given in Appendix I, AED Report 23-82.

HAZARDS AND SAFETY

Introduction

One of the objectives of this project was to convert the Yellow D to a material with sensitivity equal to or less than that of the original explosive. Therefore, propagation tests were conducted to compare the sensitivities of the conversion product and unreacted Yellow D.

Preliminary detonation tests were conducted at Tooele Army Depot, whereas more extensive sensitivity tests, by impact, friction and electrostatic charge, etc., were carried out by the Energetic Materials Division, LCWSL, Dover, N.J. A toxicology study was conducted at Edgewood Animal Testing Laboratory, Aberdeen Proving Ground, MD.

Tooele Army Depot Detonation Tests

1. Detonation Tests for Yellow D Solution

Preliminary tests were conducted to determine the detonability of Yellow D solution. Samples were prepared by dissolving the reclaimed Yellow D in water/*n*-butylamine solution and diluting with methanol. The compositon was: 35.3% Yellow D, 35.3% methanol, 17.6% *n*-butylamine and 11.8% water by weight.

Test Procedures. Solutions were charged in one-pint Nalgene plastic bottles, which were placed in fiber canisters. The space between bottle and canister was filled with sand. A blasting cap was submerged in each solution, and detonated by a time fuze. For the control standards, bottles containing pure yellow D were also detonated. Sample sizes are tabulated in Table 20. See Figures 18 and 19 for illustrations of samples prepared for the detonation tests.

Results. Bottles charged with pure Yellow D solid all exploded, without exception, however, no explosions were observed for the bottles charged with Yellow D solutions. The detonation forces of the blasting caps destroyed the plastic bottles and the fiber canisters, but did not ignite or detonate the solutions. Rather, the solutions were splashed over the ground and the retaining walls.

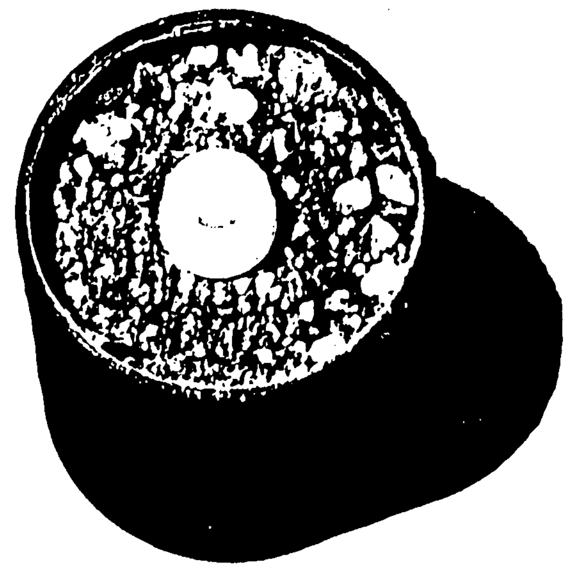
TABLE 20

SAMPLE SIZES FOR DETONATION TEST

BOTTLE NO.	SAMPLE	SAMPLE WT.(g)
1	Pure Yellow D	68.5
2	Pure Yellow D	90.0
3	Pure Yellow D	98.6
4	Yellow D Solution	92.7
5	Yellow D Solution	92.9
6	Yellow D Solution	93.5

SAMPLE #6 - LIQUID SOLUTION OF YELLOW D , SAMPLE #2 -YELLOW D POWDER

FIGURE 18



DETONATION SET UP FOR SAMPLE #6 - YELLOW D SOLUTION

FIGURE 19

2. Detonation Tests for Yellow D Solvation/Conversion Product

As each Yellow D conversion run was completed, samples were retained for the detonation tests, which were conducted at Demolition Range Number Two. The samples from runs 13 through 16 of the phase I pilot plant study (1981) and samples from runs 1 through 18 of the phase II pilot plant study (1982) were tested. Refer to the summary of these runs and their reaction conditions given in Tables 21 and 22 in the engineering effort section.

Test Procedure for The Reaction Products. The detonation test was conducted for the liquid product and also for the solid obtained by evaporating the volatiles from the liquid product. The samples were charged into 1.25-inch diameter black-iron pipe, prepared in 3-inch and 5.5-inch lengths. To increase the sample size for the propagation tests, 3-inch diameter black-iron pipes 12 inches in length were also prepared. All of these pipes were taped closed at the bottom.

For the 3-inch and 5.5-inch pipes, four tetryl pellets from M21A4 boosters, totalling 1360 grains of tetryl, were taped on top of the sample-filled pipes as explosion donors. For the 12-inch pipes, 0.63 pounds of composition C-4 explosive was packed into a separate section of pipe 3 inches in diameter and 2 inches high which was taped on top of the product-filled pipes as the donor.

In the first series of tests, the donors were placed at various gap distances from the products. In those tests where the gap distance was other than zero, the separation was provided by stacking pieces of plastic between the donor and the products. In all of the second series tests, the donors were placed on top of and in contact with the liquid product (i.e., "zero" gap distance). The donors were initiated by A7 non-electric blasting caps each attached to a timing fuze and a manually-actuated ignitor.

In order to determine whether propagation occurred between the donor and the Yellow D conversion product, the samples were placed on steel witness plates 0.25 inch thick and 10 inches square. The witness plates were supported by steel perimeter frames designed to allow the plate to deform downward from the pressure of the detonation.

Liquid Samples. Brown liquid samples were obtained from each Yellow D conversion process, and tested for detonation without alterations.

Dried Samples. Dried solid samples were obtained by allowing the evaporation of volatiles from the liquid product. These solids were loaded into the pipe fixtures for the propagation tests. Also, as standards for comparison, one test was made using sand and another using the original Yellow D powder in lieu of the solid or liquid from reactions.

Results. No indications of explosive propagation were detected for the liquid Yellow D conversion product in any of the phase II pilot plant tests. Reacted Yellow D solids caused some deflection of the witness plate whereas the liquid conversion product samples were only spattered radially away from the detonation spot "ground zero" without any signs of detonation. Results of this series of tests showed that the conversion product D solids were less sensitive to detonation from donor propagation than the unreacted explosive, and the liquid product was not susceptible at all. The results are tabulated in Tables 20 and 21. See Figures 35 through 39 for the detonation test setup and results. For a complete discussion of detonation tests see appendix G, AED Report 23-82.

TABLE 21

PHASE I CONVERTED YELLOW D CRYSTAL PROPAGATION TEST

DONOR: Four M21A4 Tetryl boosters, 1360 grains total

SAMPLE NO.	TEST DATE	GAP SIZE	PIPE LENGTH	WITNESS PLATE DEFLECTION	COMMENTS
13	1/11/82	0	3"	3/4"	
14	1/13/82	0	3"	1 1/2"	
15	1/13/82	0	3"	1 3/32"	
16	1/13/82	0	3"	Penetration	Hole diam = 1 3/8"
Sand	1/13/82	0	3"	1/4"	Standard for comparison
13	1/13/82	1/2"	5 1/2"	1/8"	Pipe recovered, ruptured
14	1/13/82	1/2"	5 1/2"	1 3/32"	
15	1/13/82	1/2"	5 1/2"	3/16"	
15	1/14/82	1/2"	5 1/2"	1/4"	
16	1/13/82	1/2"	5 1/2"	1 1/2"	Witness Plate, 5/8" crack
14	1/14/82	1/2"	5 1/2"	1/8"	Pipe recovered, split
16	1/13/82	1/2"	5 1/2"	1 7/16	
Yellow D	1/14/82	1/2"	5 1/2"	1 1/4"	Standard,
16	1/14/82	1 1/2"	5 1/2"	none	Pipe recovered, no distortion

TABLE 22

PHASE II CONVERTED YELLOW D LIQUID PROPAGATION TEST

DONORS: 5 1/2" Pipe - 4 ea M21A4 Tetryl boosters, 1360 grains total
12" Pipe - Comp 4, 284 grams (10 oz)

RUN NO.	DATE OF RUN	SENSITIVITY TEST DATE	GAP SIZE	PIPE DIAM (OD)	PIPE LENGTH	WITNESS DEFLECTION/PENETRATION
1	4/23/82	5/24/82	0	1 1/4"	5 1/2"	None
1	4/23/82	5/24/82	0	1 1/4"	5 1/2"	None
1	4/23/82	5/24/82	0	1 1/4"	5 1/2"	None
2	4/26/82	5/24/82	0	1 1/4"	5 1/2"	None
2	4/26/82	5/24/82	0	1 1/4"	5 1/2"	None
2	4/26/82	5/24/82	0	1 1/4"	5 1/2"	None
3	4/27/82	5/24/82	0	1 1/4"	5 1/2"	None
3	4/27/82	5/24/82	0	1 1/4"	5 1/2"	None
3	4/27/82	5/24/82	0	1 1/4"	5 1/2"	None
4	4/28/82	5/24/82	0	1 1/4"	5 1/2"	None
4	4/28/82	5/24/82	0	1 1/4"	5 1/2"	None
4	4/28/82	5/24/82	0	1 1/4"	5 1/2"	None
5	5/19/82	5/24/82	0	1 1/4"	5 1/2"	None
5	5/19/82	5/24/82	0	1 1/4"	5 1/2"	None
5	5/19/82	5/24/82	0	1 1/4"	5 1/2"	None
6	6/14/82	6/17/82	0	1 1/4"	5 1/2"	None
6	6/14/82	6/17/82	0	1 1/4"	5 1/2"	None
6	6/14/82	6/17/82	0	1 1/4"	5 1/2"	None
7	6/15/82	6/17/82	0	1 1/4"	5 1/2"	None
7	6/15/82	6/17/82	0	1 1/4"	5 1/2"	None
7	6/15/82	6/17/82	0	1 1/4"	5 1/2"	None
8	6/15/82	6/17/82	0	1 1/4"	5 1/2"	None
8	6/15/82	6/17/82	0	1 1/4"	5 1/2"	None
8	6/15/82	6/17/82	0	1 1/4"	5 1/2"	None
9	6/16/82	6/17/82	0	1 1/4"	5 1/2"	None
9	6/16/82	6/17/82	0	1 1/4"	5 1/2"	None
9	6/16/82	6/17/82	0	1 1/4"	5 1/2"	None

TABLE 22 (Cont'd)

PHASE II CONVERTED YELLOW D LIQUID PROPAGATION TEST

DONORS: 5 1/2" Pipe - 4 ea M21A4 Tetryl boosters, 1360 grains total
12" Pipe - Comp 4, 284 grams (10 oz)

RUN NO.	DATE OF RUN	SENSITIVITY TEST DATE	GAP SIZE	PIPE DIAM (OD)	PIPE LENGTH	WITNESS DEFLECTION/PENETRATION
10	6/22/82	6/17/82	0	1 1/4"	5 1/2"	None
10	6/22/82	6/17/82	0	1 1/4"	5 1/2"	None
10	6/22/82	6/17/82	0	1 1/4"	5 1/2"	None
11	6/24/82	7/21/82	0	1 1/4"	5 1/2"	None
11	6/24/82	7/21/82	0	1 1/4"	5 1/2"	None
11	6/24/82	7/21/82	0	3"	12"	5/8" Deflection
12	6/28/82	7/21/82	0	1 1/4"	5 1/2"	None
12	6/28/82	7/21/82	0	1 1/4"	5 1/2"	None
12	6/28/82	7/21/82	0	3"	12"	1/2" Deflection
13	6/30/82	7/21/82	0	1 1/4"	5 1/2"	None
13	6/30/82	7/21/82	0	1 1/4"	5 1/2"	None
13	6/30/82	7/21/82	0	3"	12"	1 1/4" Deflection
14	7/2/82	7/21/82	0	1 1/4"	5 1/2"	None
14	7/2/82	7/21/82	0	1 1/4"	5 1/2"	None
14	7/2/82	7/21/82	0	3"	12"	9/16" Deflection
15	7/6/82	7/21/82	0	1 1/4"	5 1/2"	None
15	7/6/82	7/21/82	0	1 1/4"	5 1/2"	None
15	7/6/82	7/21/82	0	3"	12"	5/8" Deflection
16	7/7/82	7/21/82	0	1 1/4"	5 1/2"	None
16	7/7/82	7/21/82	0	1 1/4"	5 1/2"	None
16	7/7/82	7/21/82	0	3"	12"	3/4" Deflection
17	7/8/82	7/21/82	0	1 1/4"	5 1/2"	None
17	7/8/82	7/21/82	0	1 1/4"	5 1/2"	None
17	7/8/82	7/21/82	0	3"	12"	9/16" Deflection
18	7/10/82	7/21/82	0	1 1/4"	5 1/2"	None
18	7/10/82	7/21/82	0	1 1/4"	5 1/2"	None
18	7/10/82	7/21/82	0	3"	12"	7/16" Deflection

Picatinny Arsenal Sensitivity Tests

An interim status report was provided by Picatinny Laboratory at the time of this report. Because the behavior of the reacted Yellow D after long-term storage is unknown, the final sensitivity tests will be conducted six months later. A complete test report, including the test results on the aged sample, will be provided in February 1983 as a supplement to this report.

Sample Preparation

The tests were conducted on three different samples, two liquid compositions and one solid (powder) sample. One of the liquid samples contained Yellow D reacted with n-butylamine. The other liquid sample was prepared by adding two parts of methanol by volume to one part of the Yellow D/water/n-butylamine solution. The solid sample was dried in a vacuum oven at 55°C for 24 hours before testing. The large chunks were crushed and the powder sieved through a 20 mesh sieve to obtain a homogeneous sample.

Type of Test Conducted

The following tests were performed on the samples: (1) impact sensitivity, (2) friction sensitivity, (3) electrostatic sensitivity (4) shock sensitivity, (5) differential thermal analysis, (6) explosion temperature. All six tests were made on the powders, and all but explosion temperature and friction tests were made on the liquids. Table 23 summarizes the category of sensitivity tests performed on each sample group.

TABLE 23

SAMPLE GROUPS AND CATEGORY OF
SENSITIVITY TESTS PERFORMED

SAMPLE	I.S.	F.S.	E.S.	S.S.	DTA	ET
LIQUID A	X		X	X	X	
LIQUID B	X		X	X	X	
POWDER	X	X	X	X	X	X

NOTE:

Liquid A = Yellow D/water slurry reacted with _n_-butylamine
Liquid B = Yellow D/water slurry reacted with _n_-butylamine, and diluted with methanol
Powder = solids obtained from evaporation of volatiles from reaction product
I.S. = impact sensitivity
F.S. = friction sensitivity
E.S. = electrostatic sensitivity
S.S. = shock sensitivity
DTA = differential thermal analysis
ET = explosion temperature

Test Procedures and Results

The impact sensitivity of the powdered sample was determined using the Naval Ordnance Laboratory (NOL) Type 12 impact tester. The apparatus uses a 2.5-kg steel drop weight with a 30-mg sample resting on sandpaper between two steel anvils. Drop heights corresponding to 50% and 10% probability of initiation were used as measures of impact sensitivity. The 50% initiation point was determined by means of the Bruceton up-and-down method. The 10% value was the minimum height, which resulted in initiation of the sample in at least 1 of 10 trials. The criterion for initiation in this study was any evidence of burning or detonation observed during impact or in the post-test examination of the sample. The powdered sample showed explosive reactivity, having a 50% drop height of 147 cm and a 10% value of 90 cm.

A Bureau of Explosives impact apparatus was used to ascertain that the liquid samples were insensitive to impact. The apparatus consists of a freefalling, 8-lb. hardened steel weight, a test sample holder, a steel striker, and a steel anvil.

The drop weight was released from a preselected height and the impact reaction determined. Insensitivity to impact is considered as being no explosive reaction in 10 trials using the 8-lb weight at 30 inches. No reaction was obtained in 10 trials.

The friction sensitivity test was conducted using the large-scale friction pendulum apparatus developed by ARRADCOM (formerly called Picatinny Arsenal). The apparatus consists of a fixed steel anvil and a weighted pendulum with a steel shoe. A 7-gram sample was placed on the anvil and subjected to a series of glancing blows by the shoe. The sample did not exhibit friction sensitivity. No reaction was obtained in 10 trials.

The electrostatic sensitivity test was conducted using an approaching electrode apparatus. No reaction was obtained in 20 trials at the 0.25 Joule level (0.02 microfarad capacitor charged to 5000 volts) with either the powder or liquid samples.

A modified large scale gap test apparatus was used at zero gap to assess the explosion senstivity of the sample. In this test, the material was loaded into a 5.5-inch-long steel pipe, with a 1.44 inch inside diameter and a wall thickness of 0.218 inches. The bottom of the pipe was closed with plastic tape. A donor (booster) explosive was used to provide sufficient explosive shock pressure to the test samples. The donor consisted of two pentolite (50/50 PETN/TNT) pellets, each 2 inches in diameter and 1 inch long. It was placed on top of the pipe and initiated with an electric detonator.

In these tests the criterion for an explosion was any rupture in the 0.375-inch mild-steel witness plate, which was placed at the end of the steel pipe away from the point of initiation and separated from it by a spacer 0.063 inches thick. No explosion was reported if the plate was only distorted. (In standard evaluations the criterion for explosion is formation of a clean hole in the witness plate).

Simultaneous DTA/TGA (weight loss) measurements were obtained as a function of temperature with a Mettler TA-2 thermoanalyzer at a heating rate of 10°C/min in static air. The thermogram for the powdered sample revealed that the material underwent an endothermic reaction followed by a large exothermic one. The exotherm started at 192°C and peaked at 241°C. The liquid composition, n-butylamine/methanol/Explosive D, had four endotherms (one large endotherm followed by three small ones) and two small exotherms. The thermogram for the other liquid sample showed only one large endotherm followed by two small exotherms.

The explosion temperature test was conducted by immersing a copper blasting cap containing approximately 40 milligrams of the powdered sample to a confined state to a fixed depth in a molten metal bath. Time-to-explosion was determined by measuring the time required for the blasting cap to rupture. The temperature of the 5-second point is usually reported. The 5-second value for the powdered sample was 279°C. For comparison purposes, the 5-second value for TNT is in the range of 339°C and 353°C. (The 5-second value for Yellow D is not available at the present time.)

Summary of Test Results

An analysis of the zero time test data indicated that the liquid samples would not present an explosive hazard if subjected to impact, nor sustain an explosion if subjected to shock. Although the dry powdered sample exhibited explosive reactivity, the test data show that the dry powder is much less sensitive to shock than Yellow D. The data indicate that an explosion in the powdered material might be initiated but would not propagate or sustain a high order detonation if subjected to shock. Test results are summarized in Table 24. For the detailed discussion of senstivity tests, see Appendix F, AED Report 23-82.

TABLE 24

SENSITIVITY DATA FOR DESENSITIZED EXPLOSIVE D
(Zero Time)

Sensitivity Test	Results		
	Powder from n-butylamine/ Explosive D	Liquid from n-butylamine/ Explosive D	Liquid from n-butylamine/ Methanol/Exp. D
Impact (ERL, Type 12)			
50% firing height (cm)	137		
10% firing height (cm)	90		
Impact (Bureau of Explosives)			
8 lbs at 30 in.		No reaction	No reaction
Friction			
Steel shoe	No reaction		
Electrostatic			
0.25 Joule	0/20	0/20	0/20
Shock (Large Scale Gap)	Ruptured plate	No reaction	No reaction
DTA			
Endotherm - onset (°C)	127	23 24	
peak (°C)	139	100	33
onset (°C)			77
peak (°C)			90
onset (°C)			120
peak (°C)			131
onset (°C)			190
peak (°C)			212

TABLE 24 (Cont'd)

SENSITIVITY DATA FOR DESENSITIZED EXPLOSIVE D

(Zero Time)

Sensitivity Test		Results		
		Powder from n-butylamine/ Explosive D	Liquid from n-butylamine/ Explosive D	Liquid from n-butylamine/ Methanol/Exp. D
Exotherm -	onset (°C)	192	162	217
	peak (°C)	241	232	235
	onset (°C)		270	277
	peak (°C)		364	335
TGA (weight loss)				
	onset (°C)	175	30	23
	10% (°C)	229		
Explosion Temperature (°C)				
	5-sec	279		

Toxicology

A preliminary toxicity study was conducted at Aberdeen Proving Grounds. These tests have indicated a toxicity level for Yellow D of approximately one hundreth as much as predicted by Gosselin (see reference on page 2 of toxicity study plan). The approximate lethal dose for a 150-pound person would be about 1/2 pound of Yellow D conversion product, or between 1/2 ounce and 1/2 pound of Yellow D.

Besides toxicity tests on the Yellow D conversion product and its reactants (methanol, *n*-butylamine and ammonium picrate), other related tests were also performed. These were: skin and eye sensitivity; approximate lethal dose; LD 50 by dermal, oral and intraperitoneal administration; allergenic sensitization. The results suggest that direct skin contact with the product and especially with *n*-butylamine itself should be avoided, because of severe skin burns. Continued exposure to the fumes should also be avoided.

Because of the caustic nature of butylamine and the known toxicity of methanol (both components of the Yellow D conversion product) additional tests were conducted to eliminate these factors. This was done by separating the dissolved solids from the Yellow D product and running toxicity tests on the resulting mass of mixed solids, without the presence of methanol or *n*-butylamine liquids.

Literature values for picric acid itself showed more toxicity than the preliminary values for ammonium picrate and for the Yellow D conversion product. The LD 50 tests took up to six weeks because the approximate lethal dose (ALD) had to be determined first and because the animals had to be ordered and acclimatized. Allergenic tests were observed for eight weeks. A summary of toxic doses of Yellow D conversion product is given in Table 25. For the detailed discussion of Toxicology, see Appendix H, AED Report 23-82.

TABLE 25

SUMMARY OF TOXIC DOSES PER Kg OF BODY WEIGHT, OR TOXIC CONCENTRATIONS

	YD FUEL	PICRIC ACID	AMMONIUM PICRATE	n-BUTYLAMINE	METHANOL
ALD oral	0.9 to 4 g (b) rat		(0.005 to 0.05 g (c) human) >3 g (b) rat	0.6 g (b) rat	1 to 3 g (d) human
IP	0.1 to 0.6 g (b) rat		0.2 g (b) rat	0.1 g (b) rat	
dermal	4 to 10 g (b) rabbit				
LD50 oral	0.7 to 1.7 g (b) rat			0.5 g (a,d) rat 0.6 to 0.8 g (b) rat	
dermal	<2 to 3 g (b) rabbit	0.2g (d) Frog		0.6 to 2 g (b) rabbit 0.5 (a) guinea pig 0.9 (a) rabbit	
LCo inhaln.				4000 ppm (a) rat	
LDLo oral		0.1 to 0.3 g (a) cat, rabbit guinea pig			
Dermal Irritation				10 mg/24h (a) rabbit	

a Registry of Toxic Effects of Chemical Subsantaces, 1979 (NIOSH 80-111), Study Plan pg. 2

b This study.

c Predicted by Gosselin --see pg. 2 of study plan.

d Merck Index.

NOTES:

ALD Approximate lethal dose (per Kg of body weight).

LDLo Lowest lethal dose reported (per Kg of body weight).

LD50 Lethal dose (per Kg body weight) for 50% survival.

LCo Lethal concentration (such as for vapors).

Summary of Hazard and Safety Study

Hazard and safety studies were conducted by Aberdeen Proving Ground (toxicolgy), Picatinny Arsenal (sensitivity test), and Tooele Army Depot (preliminary sensitivity test).

Results from these studies verified that the product from the reaction of Yellow D/water slurry with n-butylamine is less sensitive than pure Yellow D when it is completely dried in a vacuum oven. An attempt to produce dried material from the product by solar evaporation failed to get the product completely dry.

The liquid product was totally insensitive to impact, shock and other sensitivity tests. Further sensitivity tests on aged converted Yellow D are being conducted by Picatinny Arsenal and results will be provided at a later date.

Toxicology tests detected no more toxicity for the conversion product than for the reacting components, i.e., Yellow D, n-butylamine and methanol. Additional test results will be made available from Aberdeen next year, concerning the long-range toxicity and mutagenic tests on ammonium picrate and the converted Explosive D mixture.

CONCLUSION

General

ARRCOM tasked AED to investigate and develop a process which would eliminate the solidification and plating of Yellow D on the equipment.

A literature review of past military, academic and civil work was conducted, and six possible research approaches were formulated. Laboratory work was carried out. An approach was chosen from the results obtained, and pilot plant studies were conducted. The product was subjected to sensitivity tests, solubility tests, combustion tests, toxicity tests, and effluent analysis. Briefly, the process consisted of reacting the Yellow D/water slurry with n-butylamine for one to three hours at a reaction temperature of 70°C (158°F) which produced a slightly viscous and colored oily substance. At the end of the reaction, methanol was added to produce a less viscous solution which could be then be pumped into a furnace to be burned.

The following conclusions were made from the laboratory work and the subsequent pilot plant studies. These conclusions are presented here in the order the subjects were discussed in the section on objectives and limitations.

Stability

The product has been observed for 3.5 months, and has been stable during that time, meaning that the fuel is safe to store, is not explosive in liquid form, and burns well after storage or without storage. The chromatographic pattern exhibited by the product changes gradually with time, as the undecomposed picric acid moiety continues to be degraded. These changes are slow after the initial reaction period; the chromatrogram after three weeks was nearly the same as after 3.5 months. The explosive character is due to the nitro groups in the chemical

structure. The nitro group is continuously decomposing, mainly because of the presence of excess n-butylamine. For details, see Weak Base Reaction in the Experimental Work section under Technical Discussions. Because the change that does occur is due to continued degradation of picrate and other explosive components, the product sensitivity will be tested again after one year to compare the detonation sensitivity.

Detonation Sensitivity

The liquid product does not detonate in zero gap tests. The solid residue after evaporation of volatiles is much less sensitive in impact tests (about 30% less) than Yellow D or TNT. If the solid is further heated in a vacuum for 24 hours at 55°C and crushed, the residue remains less sensitive than Yellow D or TNT. See Picatinny sensitivity test results in the Hazards and Safety section for details.

Combustion Effluent Analysis

The flue gas from combustion of the product is clear and colorless, and contains less than 5 ppm of NO or NO_x. Carbon monoxide is about 1%. See effluent gas analysis in Hazards and Safety section, for detailed discussion.

Compatibility to Materials in the Handling Equipment

The liquid product and the solid residue after evaporation of volatiles are compatible with the materials recommended for use in the handling and storage equipment over a temperature range of -15°C to 70°C. As discussed in this report, some other materials are known to be especially incompatible with the reagents (n-butylamine and methanol) used in this process. See process equipment in Pilot Plant Study section, for detailed discussion.

Solubility

The product remains liquid and does not plate solid onto the surface of equipment over the temperature range -15°C to 70°C. A saturated solution of Yellow D at any temperature will crystallize out a coating if that temperature is lowered in the presence of seed crystals. Thus the lack of saturation was proven for the product by lowering the temperature in increments with seed crystals added. In each case the seed crystals dissolved, without initiating further crystallization.

Engineering Parameters

Engineering process parameters are provided in this report based on data obtained from the pilot plant studies. Details of the engineering parameters, and handling precautions are given in an earlier section of this report.

Independent Evaluations

Picatinny Arsenal conducted the sensitivity tests and gave general approval of the process procedure. The Army Environmental Hygiene Agency animal testing laboratory supplied the toxicology report. Results of the chromatographic analysis for effluent gases were reported by the chromatography laboratory team from Brigham Young University. The product was insensitive to detonation and no more toxic than the starting components. The combustion effluent contained near zero NO_X and about 1% carbon monoxide.

Standard Operation Procedure (SOP)

SOP's for the pilot plant study and the burning test were developed based on the findings of this study. For further details, see AED Report No. 23-82, Explosive D Solvation/Conversion Project.

RECOMMENDATION

This report describes a process in which Yellow D/water slurry is reacted with n-butylamine and diluted with methanol. The final product is a non-detonating but burnable fuel. The simplicity and safety of the conversion and its ability to hold the converted explosive in solution have been demonstrated.

If no other viable methods exist for disposal of Yellow D, the chemical conversion process developed by AED should be implemented in future Yellow D demil projects.

ABSTRACT

A technique for desensitization and conversion of waste Explosive D to a combustible but non-detonable fuel has been developed. Explosive D (ammonium picrate) was reacted with n-butylamine at 75°C for one hour, then diluted with methanol. The resulting product was burned in a commercial burner, generating 253,000 BTU/gal of energy. Production rate of processing 65 pounds of Explosive D per hour was achieved.

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AN EVALUATION OF THE SEPARATED BAY CONCEPT FOR A MUNITION ASSEMBLY FACILITY

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Abstract

The Department of Energy (DOE) Munition Assembly Complex, Building 12-64, located at Pantex, TX, uses the separated bay concept to isolate adjacent bays from one another. Tests were conducted by the US Army Waterways Experiment Station (WES) to investigate the possibility of an accidental explosion in one bay propagating to an adjacent bay, and to collect data that can be used to improve future designs of this type. Tests, simulating an accidental explosion, were conducted in a full-size donor bay with a partially completed adjacent acceptor bay, and in a 1/2-scale donor bay with complete adjacent acceptor bay, access tunnels, and blast doors.

Data from these tests indicate that the separated bay concept is a cost-effective way to insure the safety of adjacent bays in case of an accidental explosion. Validation of the separated bay concept has resulted in significant cost savings for the current expansion project at the DOE Pantex facility, and should result in more cost-effective designs for similar weapon storage and assembly facilities in the future.

Introduction

The DOE is planning an expansion program at its weapon assembly facility at the Pantex plant. The new Assembly Bay Complex is designated as

Building 12-84. The existing Assembly Bay Complex, known as Building 12-64, employs a concept used for weapon storage magazines where adjacent individual bays are separated by earth fill. The distance between adjoining bays is approximately equal to 2.0 times $W^{1/3}$, where W is equal to the actual weight of explosive contained in each bay. The two methods of construction being considered for Building 12-84 are "common-wall" bays and bays separated by earth fill similar to the existing Building 12-64. Adjacent bays in the common wall facility would be separated by heavily reinforced concrete walls designed using the methods prescribed in TM 5-1300 (Reference 1). High explosive tests were necessary to demonstrate the safety of the separated bay concept before this design could be adopted. These tests and their results are described in this paper. The tests were sponsored by the Amarillo Area Office (AAO) of the DOE, and were conducted by WES personnel. The program was monitored by Mason and Hanger--Silas Mason Co., Inc., the operating contractor for the DOE Pantex plant. The test plan and specifications (Reference 2) were prepared by Gibbs and Hill/Ammann and Whitney, a joint-venture firm, under contract to the DOE to design Building 12-84. Detailed descriptions of the tests, material properties, and test data are given in Reference 3.

The purpose of the test program was to verify the adequacy of the earth-separated bays and unlaced wall reinforcement used in the design of Building 12-64. Validation of this design concept would allow continued use of present facilities as well as future construction of separated assembly bays.

The effects of gravity cannot easily be scaled; therefore, in order to investigate the breakup and fragment distribution of the reinforced concrete roof, where gravity effects are important, it was necessary to conduct a full-scale test. Blast pressures and structural response of bays adjacent to an accidental explosion can, however, be evaluated using smaller, less expensive, scale models. Thus, the test program was divided into two phases. In Phase I the test structures were a full-scale model of a donor bay, in which a high explosive was detonated to represent an accidental explosion, and a partial acceptor bay, used to evaluate damage to an adjacent assembly bay. In Phase II the structures were one-half-scale models that included two complete assembly bays, two partial bays, three air locks, and a retaining wall and ramp. Soil was placed as backfill between the donor and acceptor bays. The soil was selected and placed according to specifications that modeled the stiffness of the soil at the prototype facility at the Pantex plant.

Construction Procedures

All tests were conducted at Camp Shelby, MS. A site layout for both phases of the experiment is shown in Figure 1.

Construction procedures for Phase I followed as closely as possible the "as-built" design drawings for the existing Building 12-64 at Pantex, TX. Material properties for reinforcing steel, concrete, and backfill approximated those used in and around Building 12-64. To reduce cost, the rectangular concrete air lock entryway used in the bays at Building 12-64 was replaced with a 9-ft-diameter corrugated metal pipe. The cross-sectional area of the pipe approximated the area of the door openings in the Pantex structures. Figures 2, 3, and 4 are plan and elevation views of the Phase I test structures showing instrumentation and charge placement. A more complete description of the structures and details of the instrumentation are given in Reference 3. The roof of the donor bay was designed to hinge upward and vent gases produced by an internal explosion. The roof was 1.5 ft thick at the walls, tapered to 0.75 ft in the center, and was covered with 2 ft of soil. Heating, ventilating, and air conditioning (HVAC) ductwork and a roof vent were included in the model.

The acceptor bay structure was one-third of a prototype bay adjacent to the donor bay. The bay wall facing the donor bay and its HVAC ductwork were identical to those in Building 12-64. The floor slab was extended and its footing deepened to minimize relative motion between the two bays.

All structures in Phase II were one-half scale models of the Building 12-64 structures. There were two complete assembly bays with air locks, two simulated bay roofs, another air lock, and a retaining wall with a ramp connecting the three air locks. A plan view of the Phase II structures is shown in Figure 5. The donor bay is in the center of the figure with the acceptor bay to the left. Elevation views are shown in Figures 6 and 7. Note that in Phase II the air locks, including blast doors, are accurate one-half-scale representations of the prototype Building 12-64 air locks.

The prototype air locks function as entrance tunnels to the bays and are equipped with two sets of blast doors, one set at the bay entrance and the other at a bulkhead in the air lock approximately 5 ft from the retaining wall. For the purposes of the test, the blast doors at the donor and acceptor bay entrances were assumed to be open and the doors at the bulkheads to be closed. Thus, the air locks leading to the donor and acceptor bays were equipped with

model blast doors at the bulkheads near the retaining wall but the bay entrances were not equipped with doors. The southernmost air lock differed from the others in that it had no doors at the bulkhead and the bay entrance was closed with a 1/2-in.-thick steel plate. This air lock represented a situation in which the first set of doors at the bulkhead were left open while the second set of doors at the bay remained closed.

The three air locks were connected by a retaining wall and ramp structure as shown in Figures 5 and 7. The wall was connected by rebar dowels to the footing, the three air locks, and the ramp slab. The roof and west wall of the ramp were framed with steel S shapes and channels. Both the roof and wall were covered with 13/16-in.-thick cement-asbestos panels with an additional layer of corrugated sheet aluminum on the roof.

Two concrete slabs shown in Figure 5 were placed to the east and south of the donor bay to simulate the roofs of adjacent bays in the prototype structure.

HVAC ductwork was modeled to evaluate possible blast leakage into the acceptor bay and to properly model the vent area in the donor bay. The "penthouse" in which the actual HVAC mechanical equipment was located was modeled with a concrete slab representing the floor slab of the equipment room.

A view of the test site showing the Phase I (in the background) and Phase II (in the foreground) structures just before testing is shown in Figure 8.

Experimental Procedures

In Phase I, a 300-lb cylinder of PBX 9501 was used as the explosive charge. The charge weight equaled the explosive weight limit of the bay and was placed near the wall adjacent to the acceptor bay. The center of the charge corresponded to the center of a 390-lb sphere of TNT whose surface is 3 ft from the wall and 2 ft from the floor. In Phase II, a 37.5-lb cylinder of PBX 9501 was placed one-half the distance of the Phase I charge from the wall and floor. Using cube-root scaling, the Phase II explosive charge was a one-half-scale version of the Phase I charge. The charges were constructed at the DOE Pantex plant. Supporting calculations for performance of the PBX 9501 explosive are given in Reference 4.

Test Results

Phase I

An overall view of the Phase I donor bay immediately after the test is shown in Figure 9. The roof slab broke into two major fragments which impacted to the east and west of the donor bay. The north wall completely separated from the floor and the east and west walls and fell back onto the bay floor. The east wall was displaced and rotated away from the center of the bay, and the corrugated entrance pipe was destroyed. The south and west walls suffered much less damage.

The two roof slab fragments, each approximately 9 by 31 ft, impacted 104 ft to the east and 102 ft to the west of the bay. Analysis of high-speed photography revealed that the major roof fragment on the west side of the bay achieved a terminal velocity of 52 fps.

Two other parts of the test structures produced fragments: the concrete slab covering the entrance pipe, and the HVAC slab. The concrete slab covering the entrance was fragmented by the explosion and produced fragments with a typical size of 8 by 4 by 3 in. Fragments from the slab were measured as far as 365 ft east of the structure. Other fragments were observed at distances up to 1,200 ft but were not mapped since the slab was used to represent door mass, not to provide accurate blast door fragment information. Approximately one-half of the HVAC slab was broken into fragments. Eleven pieces, each weighing more than 50 lb, were thrown as far as 279 ft to the north of the structure.

Individual fragment locations and fragment grid areas are shown relative to the Phase I structures in Figure 10. The figure shows the locations of all fragments which impacted outside of the five grids (E, E', W, w, and W'). The fragment content within these areas was too dense to produce a legible map. Grids E, W, and w represent the east and west backfill slopes. Grids E' and W' were impact areas for the two major roof slab fragments. Details on fragment distribution within the five grids can be found in Reference 3.

The Phase I acceptor bay suffered minor wall cracking and sustained a rigid body motion. The largest crack in the wall was approximately 0.04 in. wide and was located 13 ft from the east wall and 11.5 ft from the floor. The crack pattern for the entire wall is shown in Figure 11. With the exception of the area in the four grid squares near the center of the wall, the cracks

were of hairline width. Rigid body displacement of the acceptor bay was 3.63 in. away from the donor bay with a rotation of 0.7-deg. The maximum permanent deflection of the acceptor bay wall was approximately 0.6 in.

Phase II

Figure 12 shows a posttest view of the Phase II donor bay. The roof disengaged during the test, with the east half separating and becoming a missile while the west half remained attached to the bay. In general, the north and south walls were the most heavily damaged, with extensive cracking and rotation near the corners in addition to spalling at the base of each wall. The east and west walls exhibited relatively minor vertical cracking but were also spalled near the base.

The roof separated in the center and opened in accordance with its design philosophy. Three planes of failure developed in the roof, all along a north-south axis. These failure planes included the center line of the roof where there was no reinforcement and the intersection of the roof with the east and west walls. The east half of the roof completely separated from the bay, while the west half remained attached to the bay and was folded over to the west side (Figure 12). Since fragment distribution from this one-half scale test does not scale, it is not discussed here. Details are available in Reference 3.

Damage to the Phase II acceptor bay was primarily limited to the south wall cracking shown in Figure 13. Most of the cracks shown were of hairline width. The maximum permanent deflection on the south wall was approximately 0.6 in., and rigid body displacement was about 0.8 in. away from the donor bay.

Significant damage occurred to the donor bay air lock and to the exterior ramp. All other appurtenant structures were either undamaged or suffered very minor damage. An overall posttest view of the ramp and Phase II structure is shown in Figure 14. All of the cemesto board on the walls, and virtually all of it on the roof, were destroyed during the test. The bulkhead, doorframe, and blast doors were completely removed from the donor bay air lock. In both phases, most of the venting took place through the air lock, not through the roof. The relatively massive roof was too slow to open, and the blast door bulkheads and blast doors became major fragment hazards.

Cost Evaluation

Just prior to completion of this test program, a facility consisting of seven assembly bays, a linear accelerator bay, and a support area was constructed at the DOE Pantex plant. The bays were designed with common back and side walls using structural design methods from TM 5-1300 (Reference 1) with allowable support rotations of 2 deg. The roof and air lock doors were designed for controlled venting, as they are in the earth-separated bay design. Based on actual bid prices, the estimated cost per typical bay for common wall construction is $1.2 million.

After completion of this test program, two additional facilities were designed and are presently under construction. One of these facilities consists of 11 assembly bays, a linear accelerator bay, and a support area. The other consists of 9 assembly bays and a support area. The bays were designed with earth-separated bays using results from this test program. Based on actual bid prices, the estimated cost per typical bay for an earth-separated bay is $0.7 million. Thus, the separated bay design resulted in a reduction in cost per bay of $0.5 million, or 40 percent.

There are pertinent factors which should be considered in this cost evaluation. Competition among contractors was keener when the earth-separated bays were bid. The prevailing interest rates were higher when the common-wall bays were bid. These factors indicate that the actual cost reduction is less than indicated above. Nonetheless, it is obvious that a significant cost reduction has been achieved and that the cost of the test program has been offset manyfold by the cost savings achieved on the facilities currently under construction.

Conclusions and Recommendations

The earth-separated bay configuration is a cost-effective design for munition handling facilities. Cost savings of approximately 40 percent were realized compared to common-wall designs for the same accidental explosion threat.

Ground shock, airblast, and structural response imparted to bays surrounding a bay in which an accidental explosion occurs are well within acceptable levels. However, significant fragments were produced from the donor bay

roof, blast doors, and the reinforced concrete bulkhead supporting the blast doors. Therefore, some design changes are recommended for any new facilities to be constructed.

The design of new facilities can correct the problems identified in Building 12-64 with relatively minor modifications. The roof steel should be modified by making the principal reinforcement continuous in each part of the roof and including vertical stirrups to prevent the reinforcement from pulling out of the roof slab, thus preventing the disengagement of the roof. Since much of the early venting occurs through the air lock, enlargement of blast doors would allow quicker venting of the donor bay and, thus, less impulse on the roof and walls. The reinforced concrete bulkheads supporting the blast door assembly should be redesigned or eliminated to prevent failure and, thus, prevent the fragment hazard they cause when they fail. A wall, berm, or fragment trap should be included to stop fragments projected through the air lock. The reinforcing steel details at the corners of the bay could be improved to decrease structural damage and motion and, thus, reduce loads transmitted through the soil to adjoining bays.

There are a few construction features used for the existing Building 12-64 Complex that will not, or should not, be used in any new construction. Rebar mats should not be welded because welding reduces rebar ductility. Grade-40 rebars are no longer generally available for construction; using Grade-60 bars will result in a stronger structure and less structural damage in case of an accidental explosion. There should be no rebar laps in the roof because the large roof rotations will cause failure at the laps. Use of a noncohesive sand backfill material between the bays should be continued in any new construction because this material rapidly attenuates soil stress. In general, the separated bay concept has been validated, and is strongly recommended for new construction.

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3. Volz, R. D. and Kiger, S. A., "An Evaluation of the Separated Bay Concept for a Munition Assembly Complex; An Experimental Investigation of the Department of Energy Building 12-64 Complex"; Technical Report SL-83-6, September 1983; US Army Waterways Experiment Station, Vicksburg, MS.

4. West, G. T.; "PBX 9501 Air Blast Experiments"; MHSMP-82-09, Feb 1982; Mason and Hanger, Silas Mason Co., Inc., Amarillo, TX.

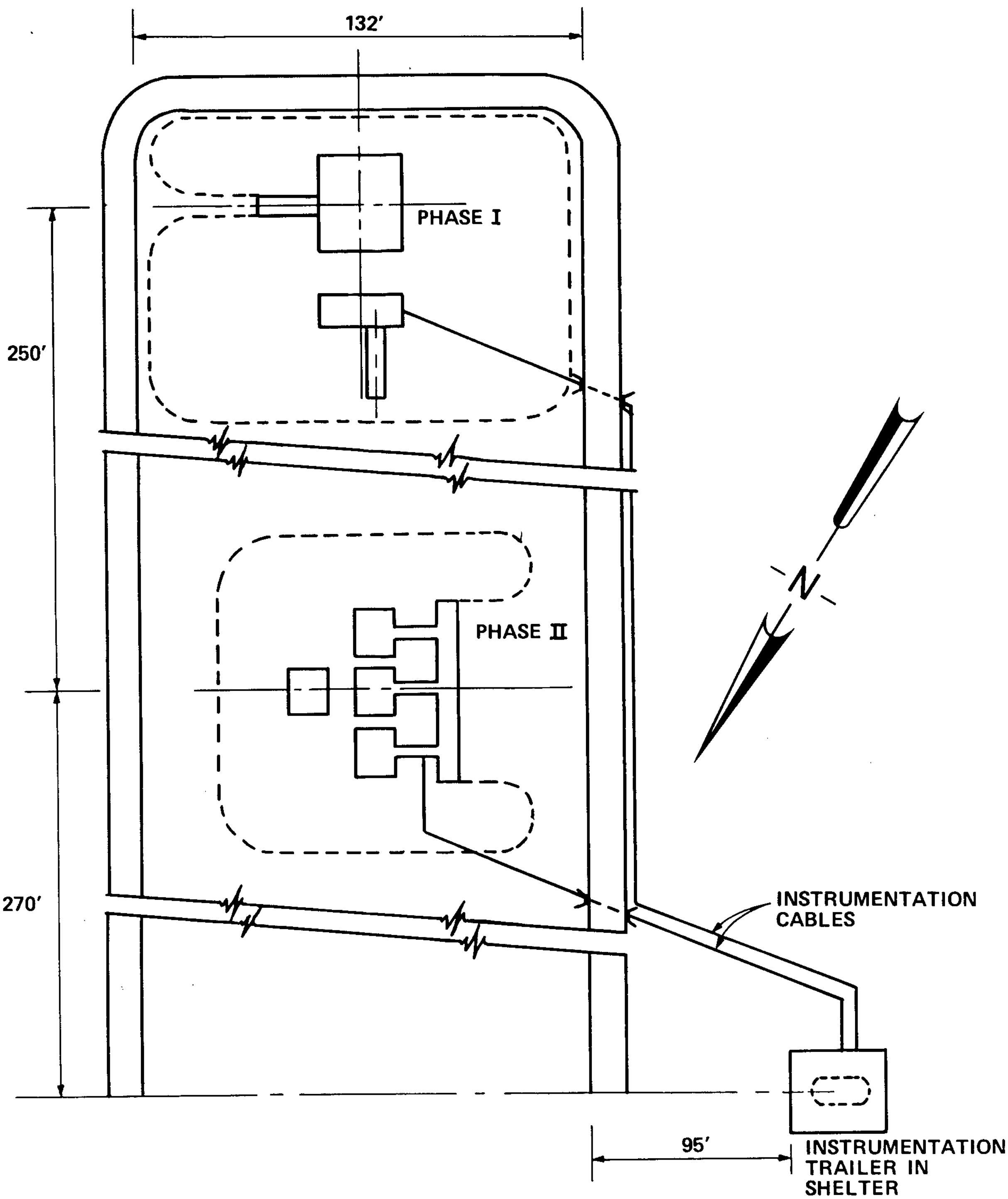

Figure 1. Test site layout at Camp Shelby, MS

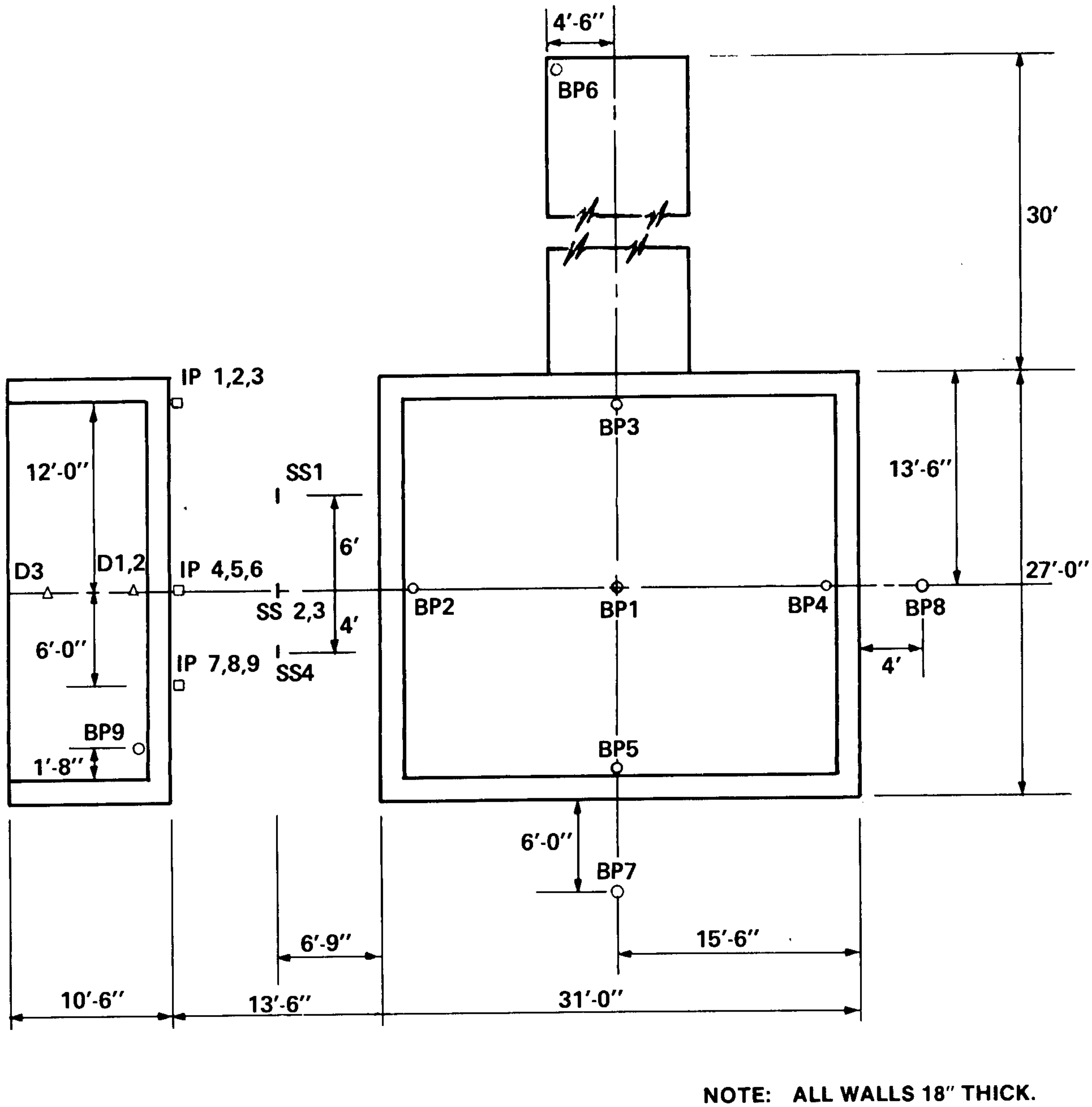

Figure 2. Plan view of Phase I donor and acceptor bays

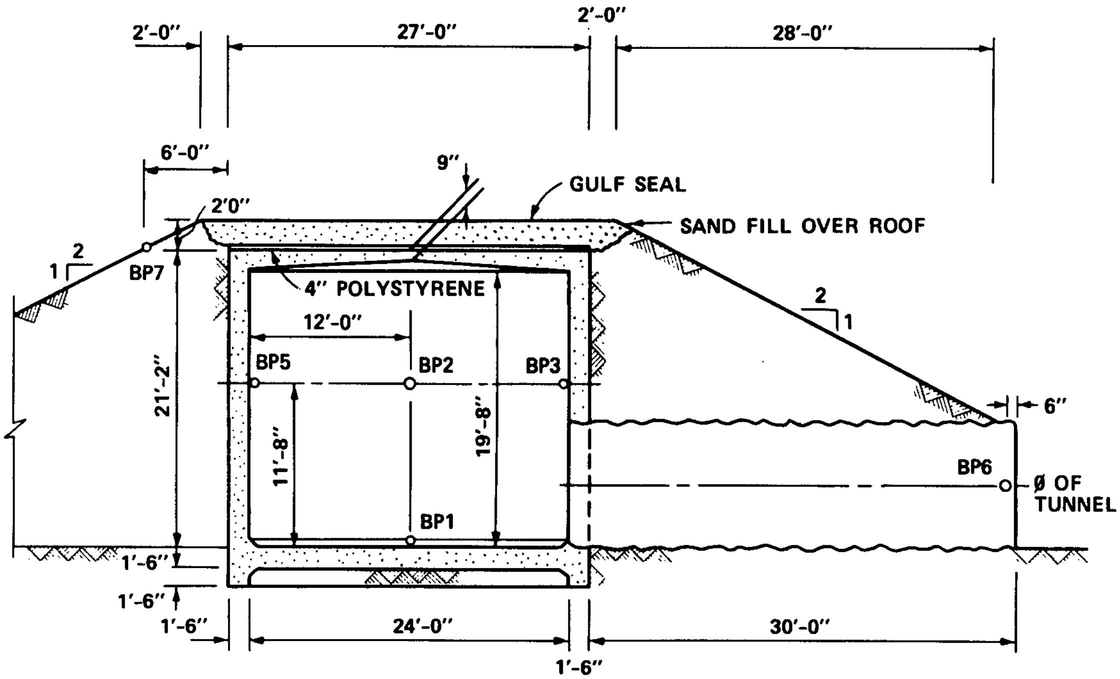

Figure 3. Elevation view of Phase I donor bay

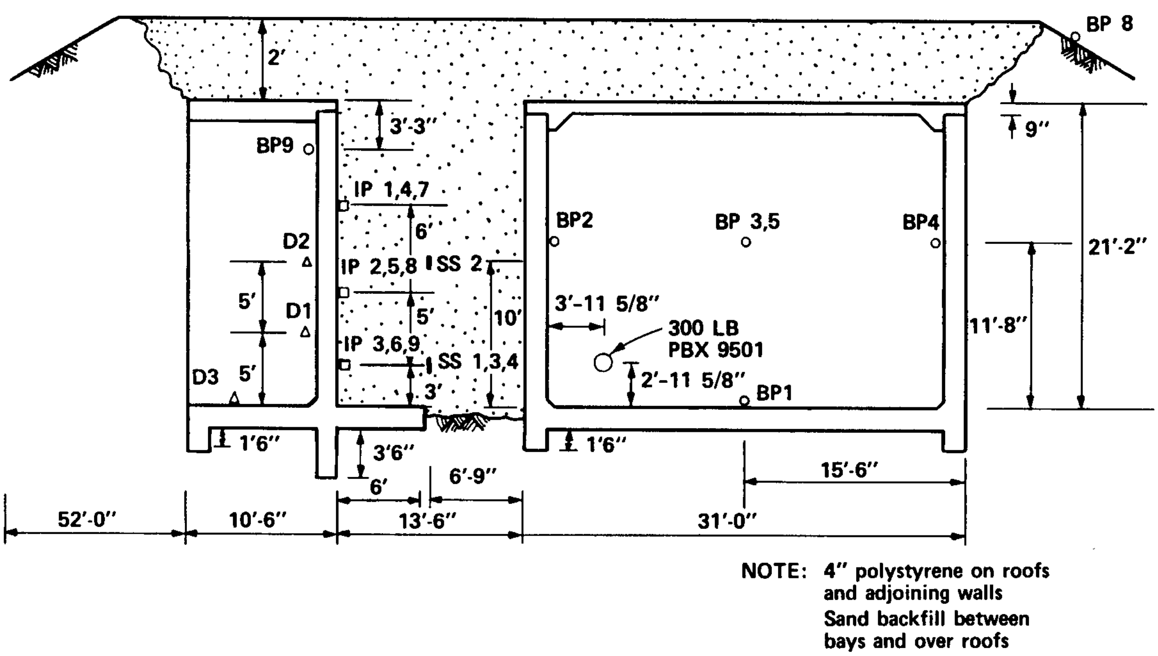

Figure 4. Elevation view of Phase I donor and acceptor bays

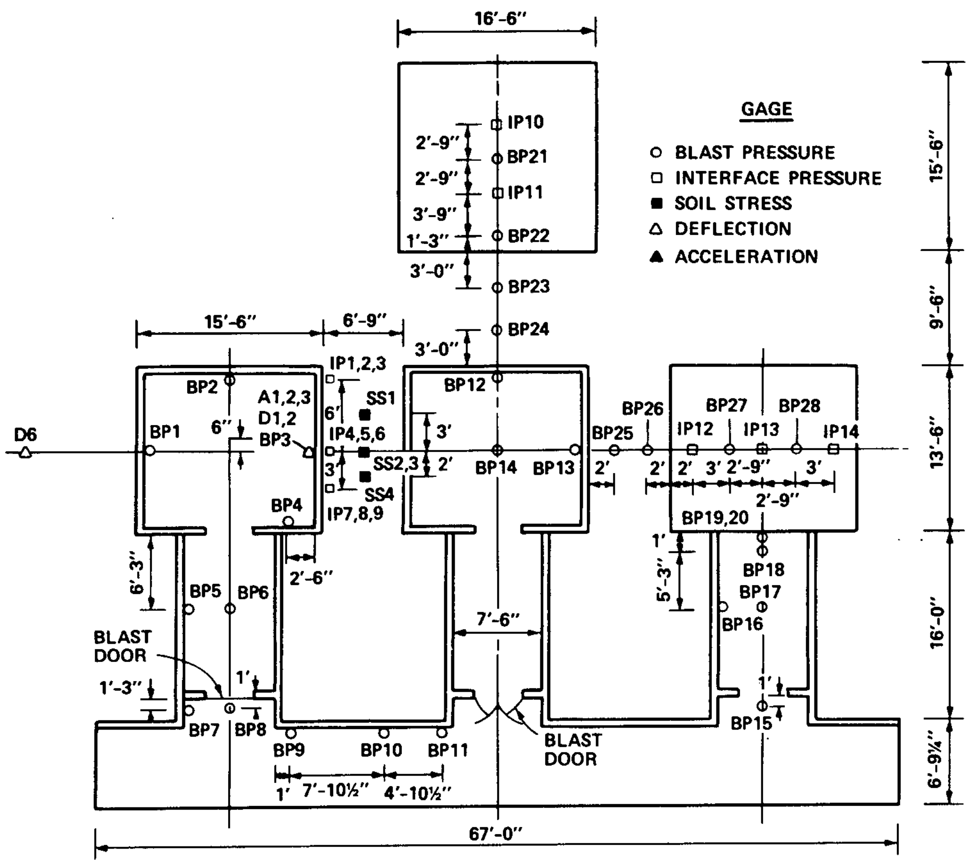

Figure 5. Plan view of Phase II structures

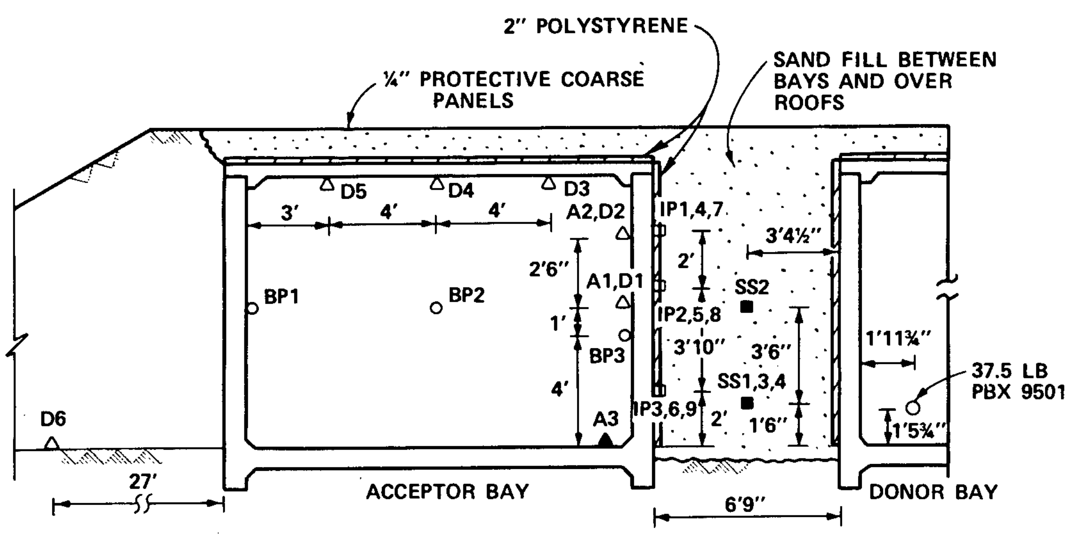

Figure 6. Elevation view of Phase II donor and acceptor bays

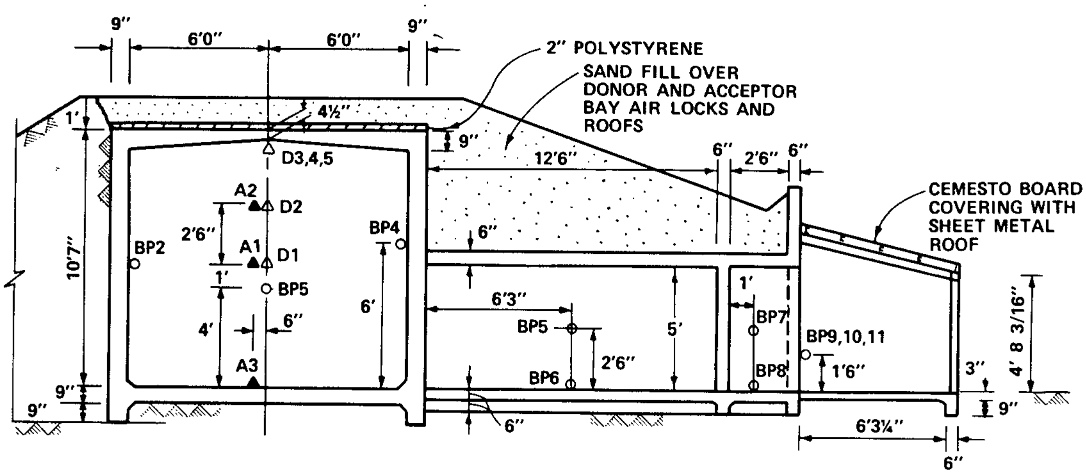

Figure 7. Elevation view of Phase II acceptor bay

Figure 8. View of completed structures facing southeast

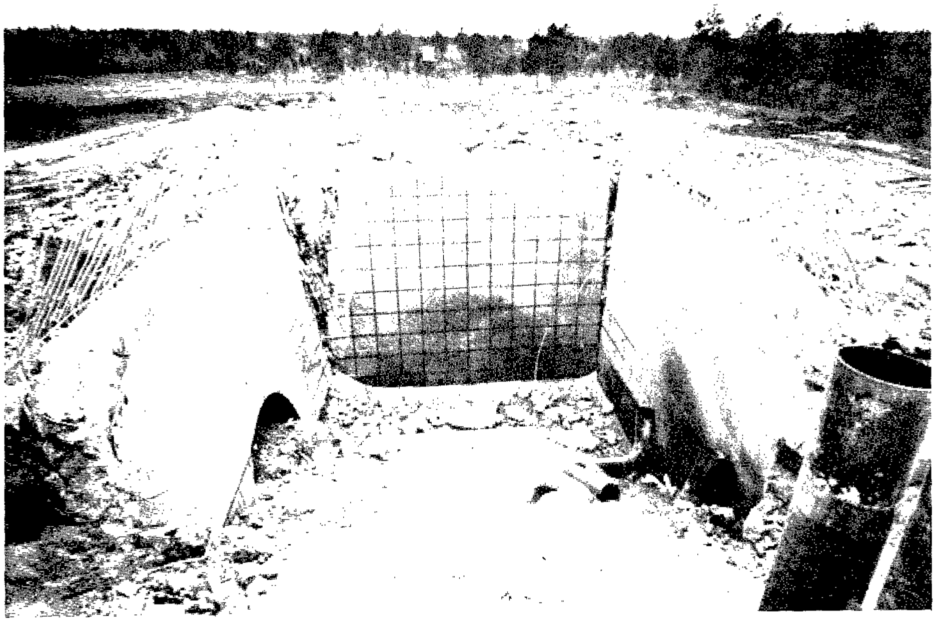

Figure 9. Posttest view of Phase I donor bay

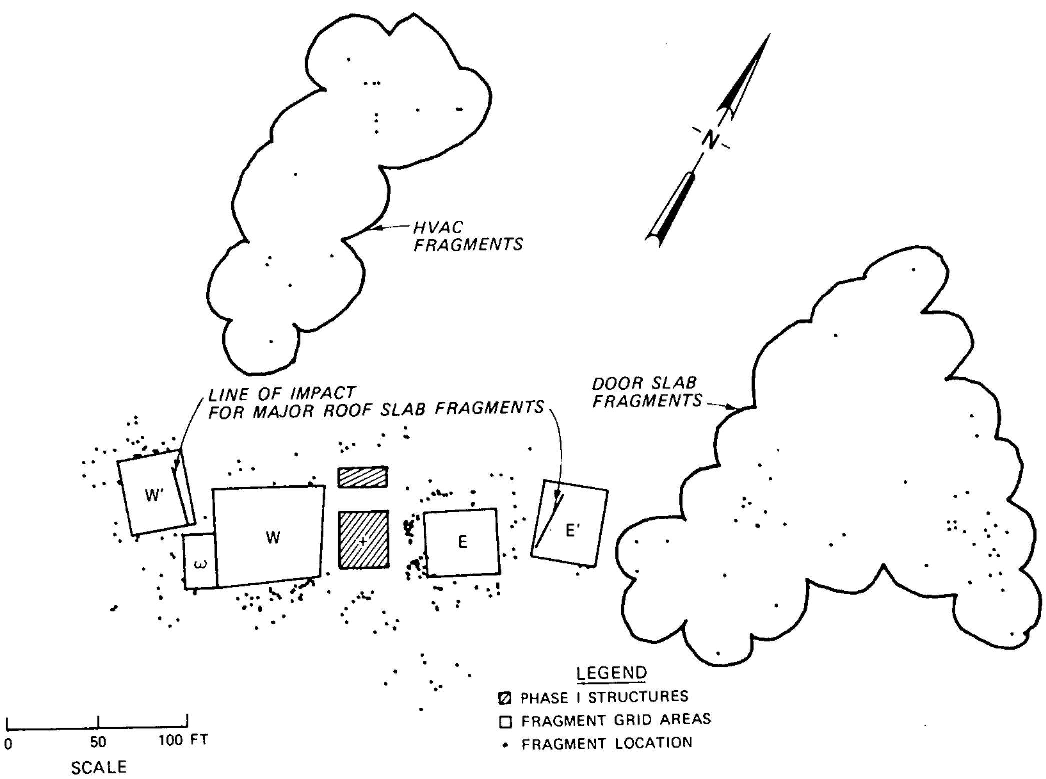

Figure 10. Individual fragments and grid areas relative to Phase I structures

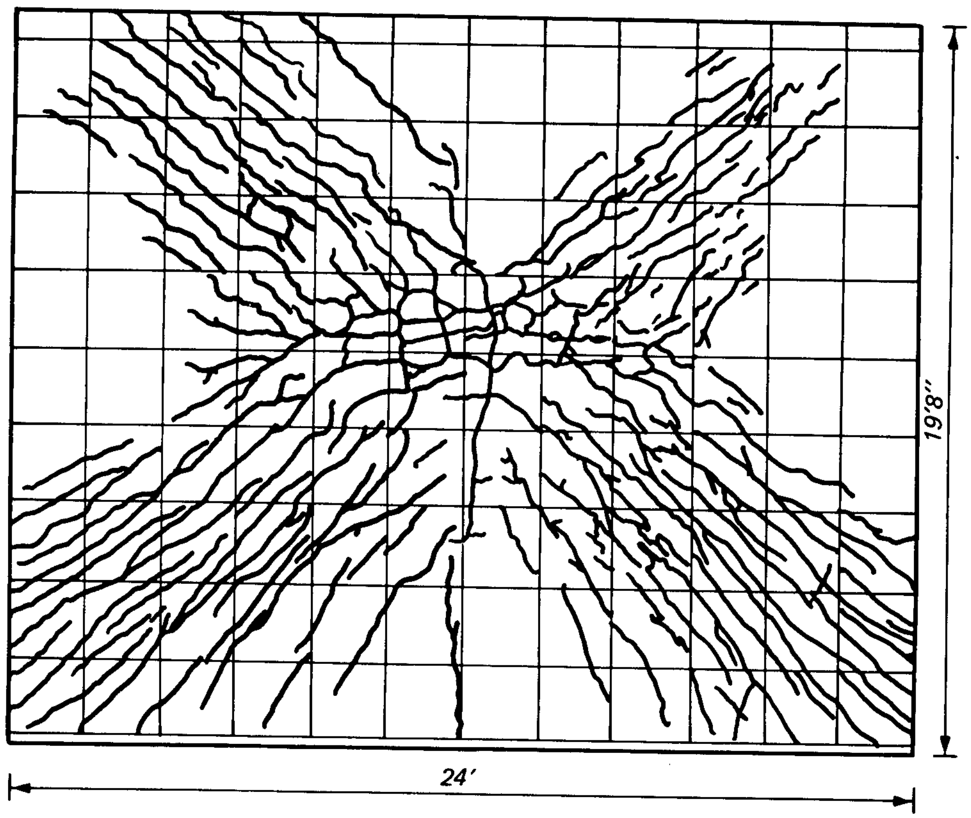

Figure 11. Posttest crack pattern on Phase I acceptor bay wall

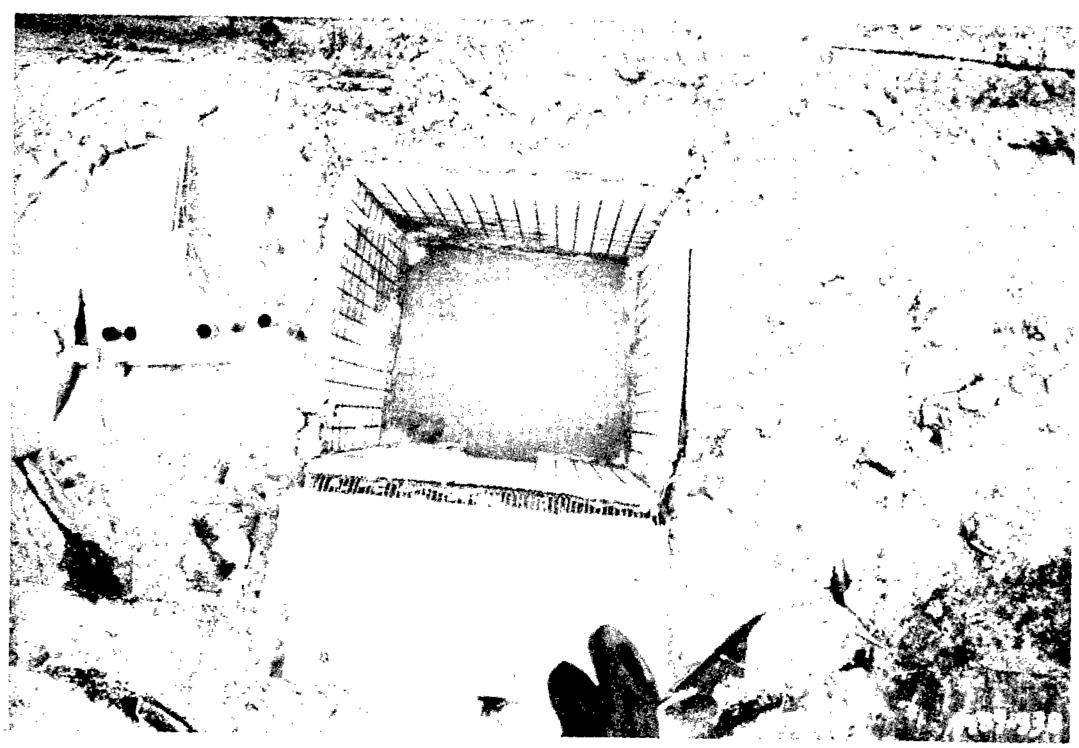

Figure 12. Posttest view of Phase II donor bay

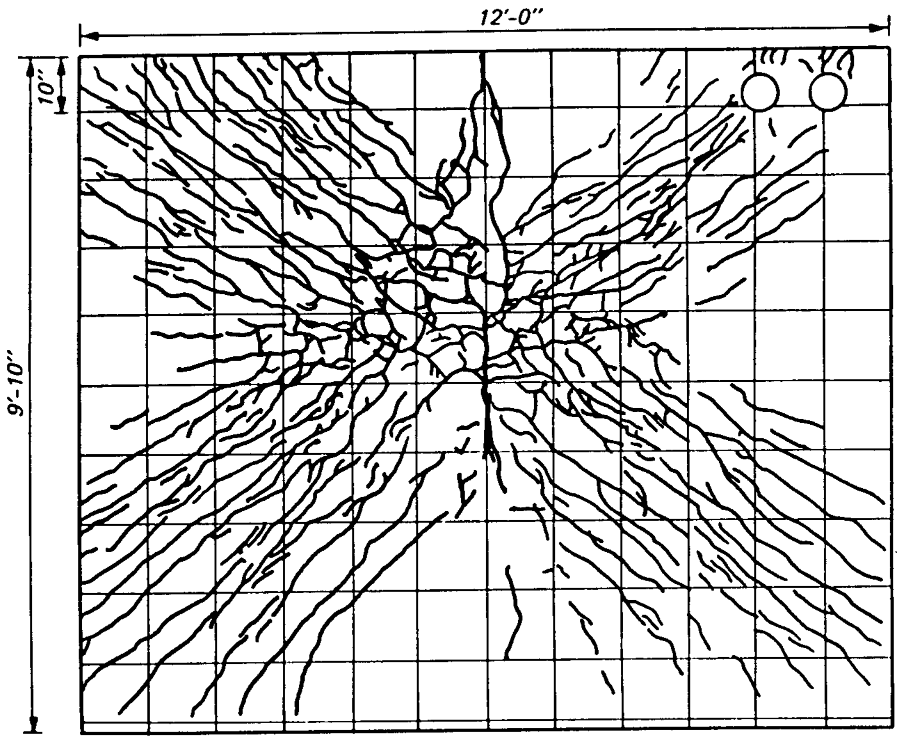

Figure 13. Posttest cracking pattern in Phase II acceptor bay south wall

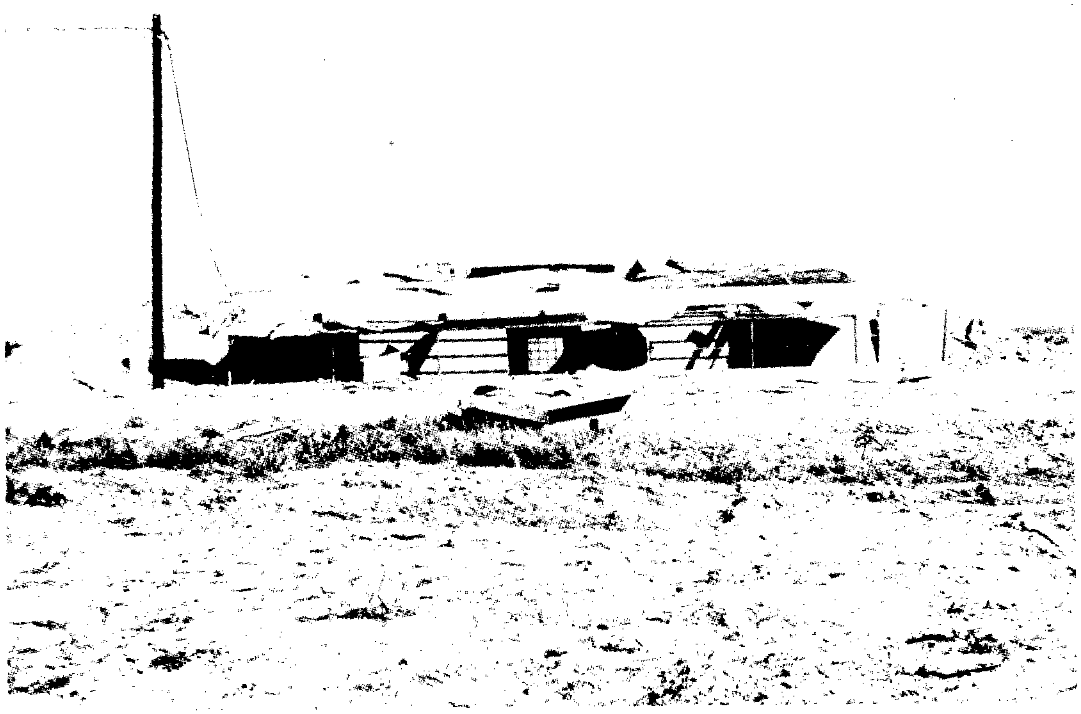

Figure 14. Posttest view of Phase II structure

EXPERIMENTAL VERIFICATION OF THE CONTAINMENT CAPABILITY OF A STEEL LINED CONCRETE MAGAZINE

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ABSTRACT

The David Taylor Naval Ship Research and Development Center operates a small explosives range at its Bethesda, Maryland site. The site at Bethesda is so small that explosive storage cannot comply with current Explosive Safety Quantity Distance (ESQD) arc requirements and therefore explosive storage requires a waiver of the ESQD requirements. Long range plans for the Center include several new buildings within 1250 feet of the explosives magazines. These sites were not approved as they were inside the ESQD arc. Safety requirements allow a considerable arc reduction if evidence exists to show that a magazine accident will be contained. This paper describes a test program which shows that the Center's magazines can be modified to contain an accidental mass detonation of a fully loaded magazine. As a result of this work, approval for a reduced arc has been given. This means that site approval for all new building at the Center is no longer tied to the explosive safety arc.

INTRODUCTION

The David Taylor Naval Ship Research and Development Center conducts research on naval ships and high performance vehicles. This research is conducted at two principle sites (one at Bethesda, Maryland and one at Annapolis, Maryland) and at several detachments located throughout the country. A portion of the research deals with the response of vehicles to explosive loads. Most of this work is done by the detachment located in the Norfolk Naval Shipyard, but a limited amount is also done on a small range at the Bethesda site. That small range is the subject of this paper.

THE PROBLEM

The site at Bethesda is made up of about 180 acres located in Montgomery County, Maryland. It is on the banks of the Potomac River just north of the District of Columbia. When dedicated in 1939 it was in a remote area of the County and the thought of an explosives range was very plausible. The range has a large test pond for underwater explosives testing, a research pit for for limited air blast work and a storage magazine. When built, the area conformed to all current safety standards and was located in a remote part of the site.

As the years went by, new buildings were erected at Bethesda. Some of these were placed reasonably close to the explosives test area but still safely outside the prevailing safety arcs. In the mid 1970's, a dramatic increase in the required safety arc was made, resulting in a new safety arc which encompassed several existing buildings, see Figure 1. This posed a

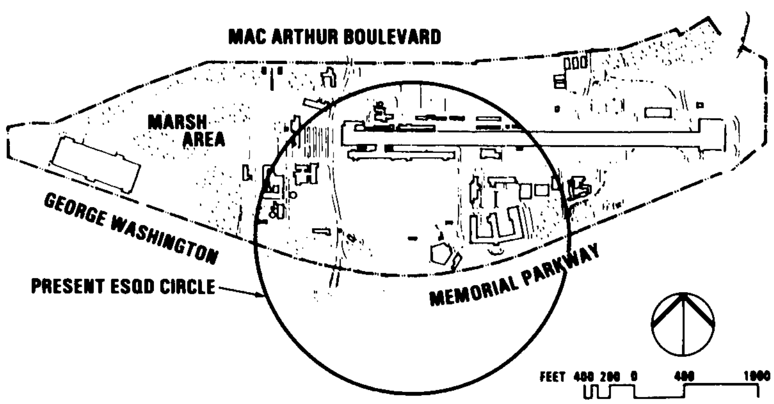

Figure 1 - Bethesda, Maryland Site Plan

minor problem for the Center in that it was necessary to obtain a waiver to permit storage of explosives closer than 1250 feet from an inhabited building. Part of the terms of the waiver reduced the storage limits to 100 pounds of high explosives and limited the individual shot size to three pounds. These limitations have caused the Center very few problems. Because of the waiver, no new construction is allowed inside the 1250 foot ESQD circle, however. Long range plans at the Center call for the siting of several new buildings inside the present ESQD circle and therefore this new construction limitation does cause the Center some problems. The building sites included in these long range plans are shown in Figure 2.

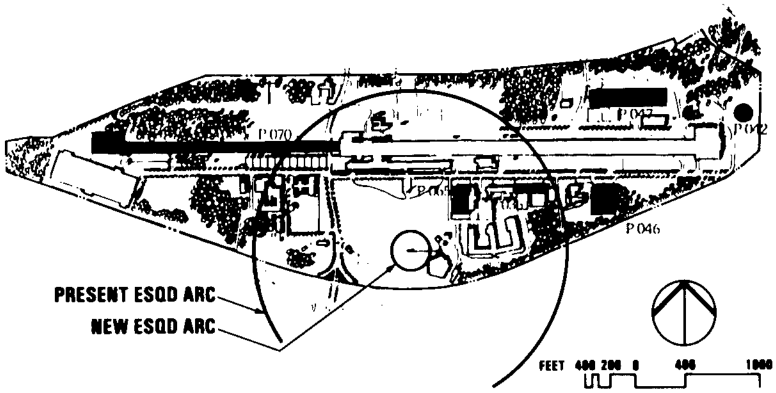

Figure 2 - Future Building Sites at Bethesda

THE SOLUTION

The best solution to the dilemma of how to site new construction to conform to the master plan without giving up the explosives testing capability is contained in the safety regulations themselves. These regulations state that distances less than 1250 feet may be used as an ESQD arc if the explosive items stored weigh less than 50 pounds per magazine and evidence exists to prove that each magazine will contain all blast fragments and debris, should an accident occur.

The arrangement of the storage magazines at Bethesda is shown in Figure 3. There are five reinforced concrete boxes, each four feet high

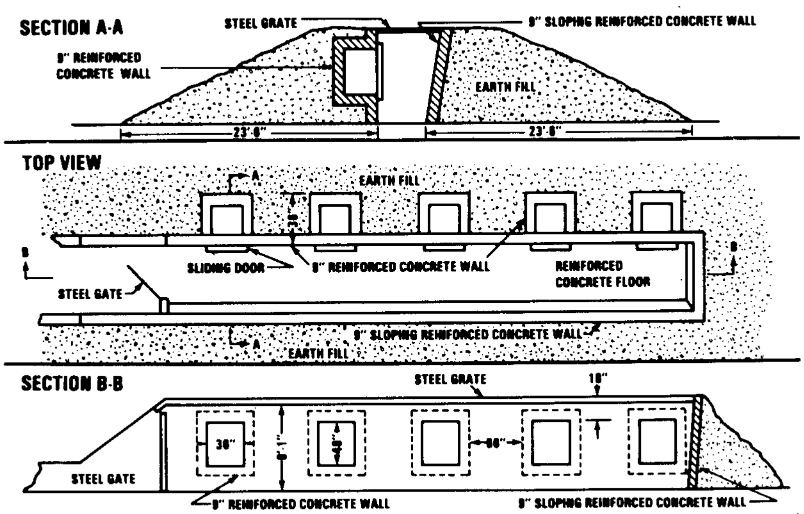

Figure 3 - Magazine Arrangement at Bethesda

and three feet square. Each magazine is separated from its neighbors by five and one half feet of conpacted fill. The top, bottom, and rear of each magazine is also covered with compacted fill. The front of each magazine has a sliding door made of wood clad with sheet steel. The doors are designed to blow off immediately in case of an accidental explosion. A wall in front of the doors is designed to stop the flight of the doors as well as to deflect the blast upwards in case of accident. The limits for each magazine were, 50 pounds of high explosives in magazines 1 and 5, 3000 detonators in magazine 3, and miscellaneous Class C material in magazines 2 and 4.

The future test needs of the Center were examined and it was decided that these needs could be met if a limit of twenty five pounds of high explosives was assigned to magazines 1, 3, and 5. This would require storage of all Class C material in magazine 2 and all detonators in magazine 4. With this change in mind the magazines were analyzed to see what effect a 25 pound blast would have on the magazines. Preliminary examination showed that the dirt cover would be sufficient on three sides for containment but that, even with the door blowing completely off immediately after the explosion, the dirt cover on top of the magazine is too thin to prevent failure of the roof. This failure would result in a shower of rock, dirt, and concrete pieces for a considerable distance. Further analysis indicated that the problem could be solved by adding a one inch steel liner inside the magazine, installing a blasting mat on top of the magazine and adding two feet of dirt to the top of the magazine. Preliminary discussions with the safety people from the Naval Sea Systems Command indicated that they would recommend use of a lesser arc if we could demonstrate containment of an accidental explosion in a magazine modified as just described.

THE EXPERIMENTAL PROGRAM

To demonstrate containment, an experimental program was conducted at the Aberdeen Proving Grounds in June 1982. As already stated, calculations indicated that a one inch liner inside the magazine would contain a 25 pound blast. Since numerous assumptions had to be made during the calculations, it was decided to increase the liner to two inches. The liner was constructed of two inch medium steel plates welded together at the corners. It was designed to fit snugly inside the magazine. Figure 4 shows the liner that was used.

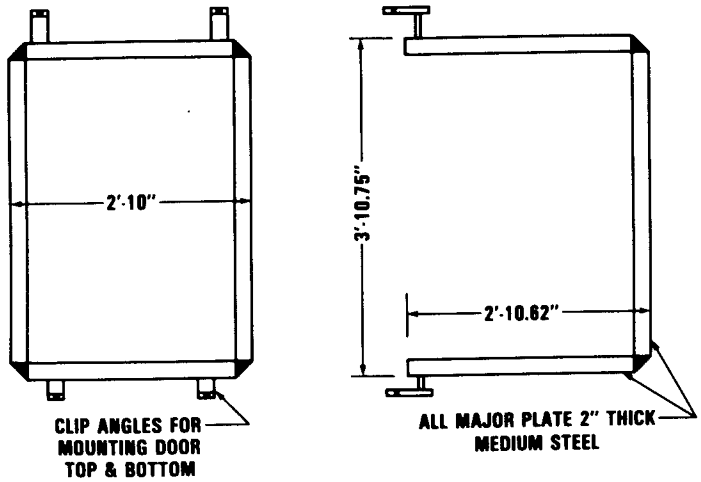

Figure 4 - Magazine Liners

The angles shown in the figure were used to hold the steel clad door in place. The door used in the test was identical to the actual doors and provided the same blast resistance, but in the interest of cost, no attempt was made to to have the door slide. The door was mearly bolted in place for the test program. In addition to the steel box, a six inch thick concrete slab, three foot by four foot was cast. The slab was not reinforced except for some temperature steel and some handling hooks. The slab was set on top of the steel box to simulate the top of the concrete magazine. It must be realized that this arrangement is much weaker than the reinforced concrete box which forms the actual magazine, so this test is more severe than if the actual magazine had been used.

The steel box with the concrete slab on top was set up on a range at Aberdeen. Dirt was piled up at least three feet around the box, but was not compacted. A blasting mat was placed over the top of the box. One problem existed with the test set up. In the actual magazine modification the blasting mat will lay on a grating with a retaining plate along the front edge. Thus it will be possible to get the full dirt coverage up to the front edge of the magazine. In these tests however there was no such retaining plate available to keep the dirt in place and therefore dirt fell away from the front edge of the box. This resulted in less than full earth cover on the front edge of the box and therefore produced a more severe test condition than in the actual magazine. This test set up is shown in Figure 5.

Figure 5 - Test Area Before the Shot

Since the magazine storage limit will be 25 pounds of high explosives, a 25 pound pentolite cylinder was used for the tests. It was placed eight inches above the floor of the steel box on a plywood table. A J-2 detonator was placed in the charge and the wooden door was set in place. The test results were recorded using two motion picture camaras running at 2000 frames per second.

Detonation of the 25 pound pentolite cylinder produced a large fire ball which destroyed the door and blew some dirt from mound near the front of the box. This would probably not have occurred if a retaining plate and the full earth cover had been used. In addition, examination of the movie film showed two objects leaving the fire ball. We believe these were parts of the door that were not consumed by the fire ball. This was confirmed by a post test check of the area near the test site. Two pieces of plywood from the door were picked up. Nothing else was found during the post test area check, and nothing else could be seen leaving the test area in the movies. The two pieces of wood were not considered a problem because the grating and blasting mat would have contained the door pieces, had the blast occurred in the magazine.

After the shot the area around the box was carefully examined. All the dirt was still on the mound, except for the small amount in the front that was just discussed. The dirt on the mound appeared undisturbed. There was no evidence that anything had breached the dirt mound. The concrete slab had failed and pieces of concrete were found on the ground in front of the steel box. All the concrete was confined to an area within 25 feet of the front of the box as shown in Figure 6. The

Figure 6 - Test Area After the Shot

entire steel box remained inside the dirt mound. The dirt did not appear disturbed in any direction a foot or more from the box. The plates that made up the box were all in tact although some of the welds had broken. This is shown in Figure 7. The test area in front of the box was carefully checked for debris but none was found except for the two pieces of the door already discussed.

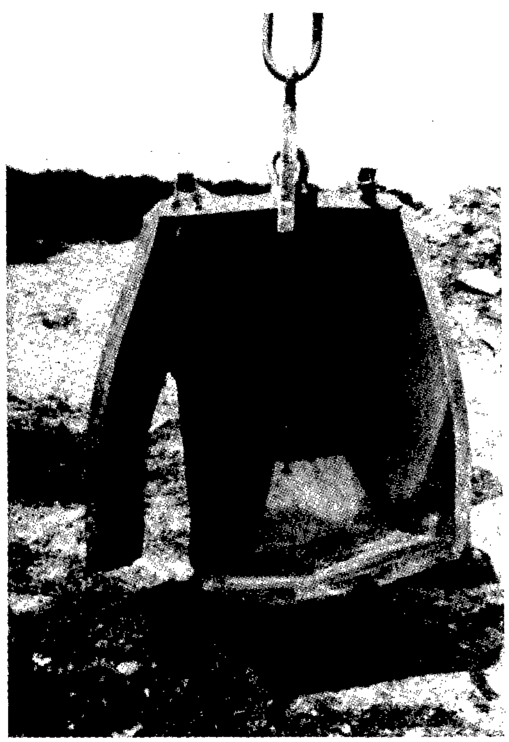

Figure 7 - Magazine Liner After the Shot

ANALYTICAL VERIFICATION

Based on these tests, a request for reduction of the required ESQD arc at the Center was sent to the Naval Sea Systems Command. Before approving this request, NAVSEA felt the need for an independent analysis of the magazine problem. This analysis was done by Mr. W. A. Keenan of the Naval Civil Engineering Laboratory at Port Hueneme. In his analysis Mr. Keenan calculated the reflected shock impluse and the gas impulse. The results of these calculations are shown in Table 1. Using these results, the dynamic response of the box was then calculated and compared to the deflections that would be expected at failure of the box. This comparison is shown in Table 2. The results of the analysis show that the roof was very near failure and the sides of the box should have failed. These calculations are consistant with the field results. As a result of this study, it was recommended that the steel liners be made slightly smaller than the concrete magazine so that the steel box could deflect without striking the concrete, thus reducing the damage to the concrete and producing less concrete debris and rubble. This recommendation has been incorporated into the magazine modification.

REFLECTED SHOCK IMPULSE

	PARAMETERS						DESIGN PARAMETERS					IMPULSE (N = 4)	
STRUCTURAL STEEL ELEMENT	W (LBS)	L FT	H FT	l FT	h FT	R_A FT	$\frac{L}{H}$	$\frac{l}{L}$	$\frac{h}{H}$	$\frac{R_A}{W^{1/3}}$	$\frac{L}{R_A}$	$\frac{i_r}{W^{1/3}}$	i_r PSI-MSEC
SIDEWALL	25	3.0	4.0	1.5	0.67	1.50	0.75	0.50	0.17	0.51	2.00	1100	3216
ROOF	25	3.0	3.0	1.5	1.50	3.33	1.00	0.50	0.50	1.14	0.90	1000	2924

GAS IMPULSE

PARAMETERS				DESIGN PARAMETERS				IMPULSE	
W (LBS)	α* LB/FT^2	A FT^2	V** FT^3	$\frac{i_r}{W^{1/3}}$ PSI $\frac{MSEC}{LB^{1/3}}$	$\frac{W}{V}$ LB/FT^3	$\frac{A}{V^{2/3}}$	$\frac{\alpha}{W^{1/3}}$ $\frac{PSF}{LB^{1/3}}$	$\frac{i_g}{W^{1/3}}$	i_g PSI-MSEC
25	11.7	12	26	1000	0.96	1.37	4.0	50***	146

TOTAL IMPULSE

STRUCTURAL STEEL ELEMENT	REFLECTED SHOCK IMPULSE PSI-MSEC	GAS IMPULSE PSI-MSEC	TOTAL IMPULSE PSI-MSEC
SIDEWALL	3216	146	3362
ROOF	2924	146	3070

NOTES
- * 2" TIMBER @ 35 PCF METAL FACING @ 3/32" (ASSUME)
- ** ACCOUNTS FOR 2" THICK STEEL BOX INSIDE EXISTING REINFORCED CONCRETE MAGAZINE
- *** CONSERVATIVE BASED ON NCEL CRITERIA

Table 1 - Impulse Calculations

STRUCTURAL ELEMENT	TOTAL* IMPULSE PSI-MSEC	t (IN)	L (IN)	H (IN)	M_u** $\frac{\text{IN-LB}}{\text{IN}}$	$\frac{L}{H}$	$\frac{Y}{H}$	Y (IN)	r_u# (PSI)	m*** $\frac{\text{PSI-MSEC}^2}{\text{IN}}$	X_m## (IN)	X_u### (IN)
SIDE WALL	3380	2.0	44	34	48000	1.30	0.79	26.9	683	1484	5.74	3.88
ROOF	3070	2.0	34	32	48000	1.06	0.64	20.5	1142	1484	2.78	3.00

NOTES

* TAKEN FROM TABLE 1

** BASED ON $F_{YS} = 40000$ PSI, $F_{YD} = 1.2\ (F_{YS}) = 48000$PSI

\# $R_U = \frac{5(M_U + M_U)}{Y^2}$

*** MASS OF STEEL PLATE, NEGLECTING CONCRETE WALL AND SOIL

\## $X_M = \frac{I^2}{2MR_U}$

\### BASED ON 10 DEGREE SUPPORT ROTATION AS FAILURE OF STEEL PLATE

Table 2- Dynamic Response of the Box

FINAL DISPOSITION

As a result of this program, a reduction of the ESQD arc at the David Taylor Naval Ship Research and Development Center has been approved by the Department of Defense Explosives Safety Board pending completion of the magazine modifications described in this paper. Those modifications have been completed and we are now operating under the new arc. We are very pleased with the outcome of this program and its effects on our operations. However the real reason for sharing it with you is that it provide an experimentally verified data point of a very simple structure which can be used to check any future magazine response programs that are developed.

ABSTRACT FOR THE

TWENTY-FIRST EXPLOSIVE SAFETY SEMINAR

"Structural Design for Blast-Containment Facilities"

by

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A 1/4-scale structural model was designed to represent a maintenance bay in a large munitions storage complex. Following construction, the model structure was tested by detonating a high explosive inside it, simulating the accidental detonation of a stored weapon. Two tests were conducted on the model. The model survived the first test with only minor structural damage. Before the second test, the inside of the maintenance bay model was coated with a sealant which was at least partially combustible. The burning of this combustible material produced a significant increase in the quasi-static gas pressure inside the maintenance bay and caused structural failure in the second test. These data indicate that the structural design used in this test is adequate to contain an accidental explosion. However, an added factor of safety could be obtained by strengthening the corner reinforcement detail where the maintenance bay roof connects to the walls.

STRUCTURAL DESIGN FOR BLAST-CONTAINMENT FACILITIES

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Introduction

In large weapon-handling facilities it is often necessary to have a maintenance room which would contain the effects of an accidental high-explosive (HE) detonation. If chemical, biological, or nuclear weapons are being maintained it is extremely important that these contaminants not be allowed to escape to the atmosphere or into other parts of the storage facility. In order to contain these contaminants, the structure must be designed elastically or to sustain only minor structural damage during an accidental detonation.

A containment structure can be designed using very conservative design procedures; however, such a structure would be relatively expensive. A more economical structure can be designed using a less conservative design procedure. The design of the structure can then be verified by testing a scale model.

Scope

An adequate, but not overly conservative design for a blast containment reinforced concrete structure is described. This structure represents a weapons maintenance bay and will contain the blast pressure and late-time gas pressure from the detonation of 256 lb of TNT. Verification tests (Reference 1) were conducted on the 1/4-scale structural model shown in Figure 1. Results of two internal blast tests and three static pressure tests are discussed.

Structural Design

Since a 1/4-scale model was constructed and tested, all design calculations will be for the model. Detailed design calculations are provided in Reference 1. To obtain approximate prototype dimensions, times, forces,

pressures, and charge weights, multiply by 4, 4, 16, 1, and 64, respectively. Note that gravity effects (weights) are not accurately scaled in the model. However, the added stresses due to gravity in the prototype will help hold the structure together during an internal explosion. Thus, results from the model tests will be design conservative. All calculations are for dynamic loads only; dead and live load effects are not included.

The structural model was designed to contain the effects of the internal detonation of a 4-lb TNT sphere. A 20-percent safety factor on charge weight was used for design calculation purposes. This gives a design charge weight of 4.8 lb. The design location for the center of the charge was 7.5 in. above the floor and the charge could be located no closer than 1.61 ft from any of the four walls. Each structural element was designed for the worst possible charge location for that element.

The structure was designed to resist the airblast pressure from the detonation plus the gas pressure caused by combustion byproducts and heating the air in the room. The peak gas pressure is a function of the ratio of the charge weight to the volume of the room. This pressure was determined from the Suppressive Shields Handbook (Reference 2). For a charge weight-to-volume ratio of 0.005 lb/ft^3, a gas pressure of 46 psi was determined.

Since the maintenance bay is completely enclosed, the gas pressure will not vent; therefore, its duration is long compared to the period of the structural elements. Thus, the structure was designed to withstand both the impulsive blast pressure and static gas pressure of 46 psi.

The blast loads on the end walls and roof of the structure were computed for several different charge locations. The average blast impulse load on the end wall for each location used was 421 psi-msec, and the average blast impulse load on the roof slab for each location was 188 psi-msec. Blast loads were calculated using the computer code described in Reference 3 and are the average impulse loads on the element being analyzed. These loads include the effects of reflections off of the other walls, roof, and floor.

Duration and pressure associated with the blast impulses were computed using the procedures from TM 5-1300 (Reference 4). The duration of this pressure pulse is given by:

$$t_o = (t_A)_F - (t_A)_A + 1.5\ (t_o)_F \tag{1}$$

where

t_o = Duration associated with blast impulse

$(t_A)_F$ = Arrival time of blast at point on wall (roof) farthest from charge

$(t_A)_A$ = Arrival time of blast at point on wall (roof) nearest to charge

$(t_o)_F$ = Positive phase duration of pressure pulse at point on wall (roof) farthest from charge

$(t_A)_F$, $(t_A)_A$, and $(t_o)_F$ were determined from Figure 4-12 in TM 5-1300 (Reference 4).

The duration of the blast pulse for the end wall was calculated based on a charge location 7.5 in. above the floor and 1.61 ft away from the center of the length of the end wall. For the roof slab, the charge location was at the center of the room 7.5 in. off of the floor.

The blast pressure durations for the end wall and roof slab were 3.00 and 7.28 msec, respectively. The peak pressure associated with the impulse was approximated by:

$$P = \frac{2I}{t_o} \tag{2}$$

The average peak blast pressures for the end wall and roof slab were 281 and 52 psi, respectively. It was assumed that the gas pressure would build up to its peak value by the time the blast pressure decreased to that value, as shown in Figures 2 and 3 for the end wall and roof slab, respectively.

Once the loadings were determined, a single-degree-of-freedom (SDOF) model was used to analyze each element. The end wall is supported at the roof and floor and another support is provided by the collar (Figure 1) 3 ft above the floor. This collar represents the roof of the remainder of the building which would be at a lower height. The maintenance bay is taller to provide room for overhead cranes. The end wall was analyzed as a one-way slab spanning between the floor and the collar. The roof slab was analyzed as a two-way slab. The same general procedure was used to analyze the end wall and

roof slab. References 5 and 6 were used in this analysis.

Once the structural elements were properly designed to provide flexural and shear resistance, a layer of reinforcement steel was provided at the center of the roof, walls, and floor to carry the net tensile forces generated by the internal explosion. Details of the design calculations are given in Reference 1.

Test Structure

The one-quarter scale model structure is shown in Figure 1. The walls, roof, and floor of this structure are 9 in. thick and contain three layers of reinforcement in each direction. Reinforcement steel ratios for the structural elements are shown in Table 1, and reinforcement steel placement is shown in Figure 4. Also summarized in Table 1 are the shear steel ratios in each structural element. Since the structure was subjected to an internal detonation, the corners were designed to resist an opening moment. The diagonal bars shown in Figure 4, sheet 6, were designed to increase the opening moment capacity of the corner between the floor and the wall slab. Similar bars were provided at wall-to-wall corners and wall-to-roof corners.

Test Descriptions

Two HE tests and three static pressure tests were conducted on this model structure. The test configuration and instrumentation layout for the first HE test are shown in Figure 5. The inside surfaces of the structure were coated with a polyurethane sealant following Test 1 and prior to Test 2. The test layout for Test 2 was the same as for Test 1 except that the charge was placed opposite the center of the length of the back wall instead of in the corner.

Static air pressure tests were conducted before HE Test 1, after HE Test 1, and after application of the polyurethane sealant. Air was pumped into the structure until a pressure of 10 psi was reached inside. The pressure was then monitored as the air leaked out to obtain a record of the leakage rate at a reference static pressure of 10 psi. This helped to evaluate the amount of structural damage from HE Test 1.

Test Results

In HE Test 1, there was very little damage to the maintenance bay model. There was a small crack on the top of the roof near the center of the short

span and running in the long-span direction. On the inside of the structure, the cold joint between each of the four walls and the roof had opened slightly; however, no crack could be seen at the cold joint from the outside of the structure.

Two blast pressure gages were placed on the floor of the model to monitor the gas pressure buildup. One gage registered a peak gas pressure of approximately 37 psi and the other about 39 psi. These values compare well with the predicted gas pressure of 41 psi for a 4-lb TNT charge in this volume. A Bourdon gage mounted to the door of the structure was used to monitor very late time pressure inside the structure after the test. Approximately 2 minutes after the test, the pressure in the structure was about 2 psi on the Bourdon gage. Calculations indicate that the heat in the air will be absorbed by the concrete quickly enough to cause this decrease in pressure in a time reasonably near 2 minutes.

Static air pressure tests were conducted before and after HE Test 1. Figure 6 shows soap bubbles caused by escaping air during the pressure test after HE Test 1. These bubbles highlight extremely small (barely visible) cracks which extended through the roof of the structure. The large crack near the center of the roof did not leak because it did not extend through the thickness of the roof. Results of static air pressure tests before and after HE Test 1 are shown in Figure 7. These tests indicate that the structure was not airtight even before testing and that damage sustained by the structure during the detonation approximately doubled the leakage rate.

A polyurethane sealant was applied to the inside surfaces of the structure in an attempt to make the structure airtight. Figure 7 shows the results of the air pressure test after application of the sealant. Although the sealant did not stop the leakage, it did significantly decrease the rate.

A second HE test was conducted on the model after application of the sealant. During HE Test 2, escaping gas was heard and smoke was observed escaping from the structure along the joint between the back wall and the roof slab. This area was the most severely damaged area of the structure. The sand backfill above this area was blown away and pieces of concrete were found behind the structure. Damage to the joint between the back wall and roof is shown in Figure 8.

Figure 9 is a photograph of the damaged joint taken from inside the structure. As shown in Figure 9, the 90-degree bends at the bottoms of many of the stirrups in the roof slab were straightened out. Figure 9 also shows the inside surface of the sealant, which was charred.

No. 3 diagonal bars were located along the joints between the walls and roof slab on a 7-in. spacing. These bars were provided to prevent the joints from opening during the test. The placement of these bars is similar to the placement of the bars between the walls and floor slab, as shown in Figure 4. Twenty-two of the diagonal bars in the joint between the back wall and the roof slab failed during the test. The inside of the cold joint between the roof slab and each of the walls was opened by the internal pressure. The permanent deflection of the center of the roof was 8.25 in. There was no damage to the floor slab or the portion of the wall beneath the collar.

Blast pressure gages indicated a rise to an initial gas pressure of approximately 45 psi and most of the gages indicated that the pressure was beginning to rise significantly between 1 and 1.5 seconds. These records indicate that the maximum gas pressure inside the room was approximately 150 psi. Burning of the sealant apparently caused an immediate increase in gas pressure above that caused by the HE, and the gas pressure gradually increased as more of the sealant burned. The failure seems to have occurred late in time when the pressure was much higher than the 46-psi design pressure.

Conclusions

These tests indicate that the maintenance bay can withstand an internal detonation of 256 lb of TNT with only minor damage. A polyurethane sealant applied to the inside of the structure did a good job of sealing it; however, the sealant burned, causing an increase in gas pressure resulting in a failure of the corner between the roof slab and the back wall. The tests demonstrated the need for minimizing the amount of combustible materials in a containment facility. The corner detail could be modified so that the corner strength more nearly matches the roof slab strength to provide an added factor of safety in the design.

REFERENCES

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Department of the Army; "Suppressive Shields Structural Design and Analysis Handbook;" HNDM-1110-1-2, US Army Engineer Division, Huntsville, Huntsville, Ala.

Levy, Stuart; "Improved Computer Program to Calculate the Average Blast Impulse Loads Acting on a Wall of a Cubicle;" Technical Report 4070, May 1970; Picatinny Arsenal, N. J.

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Biggs, J. M.; "Introduction to Structural Dynamics;" 1964; McGraw-Hill Co., New York, N. Y.

Crawford, R. W., Higgens, C. J., and Bultman, E. H.; "The Air Force Manual for Design and Analysis of Hardened Structures;" Technical Report AFWL-TR-74-102, 1974; Air Force Weapons Laboratory, Kirtland AFB, N. Mex.

Table 1

Steel Ratios in Maintenance Bay Model

Type of Steel	Direction	Location	Roof	Walls*	Floor
Reinforcing bars	Short	Inside face	0.0038	0.0038	0.0038
		Center	0.0069	0.0038	0.0069
		Outside face	0.0069	0.0038	0.0069
	Long	Inside face	0.0038	0.0017	0.0038
		Center	0.0069	0.0038	0.0069
		Outside face	0.0069	0.0017	0.0069
Stirrups	--	Near supports	0.0040	0.0050	0.0040
		Near center	0.0020	0.0040	0.0020

Note: Ratios are based on an effective depth of 8.31 inches.
* Excludes area near the door.

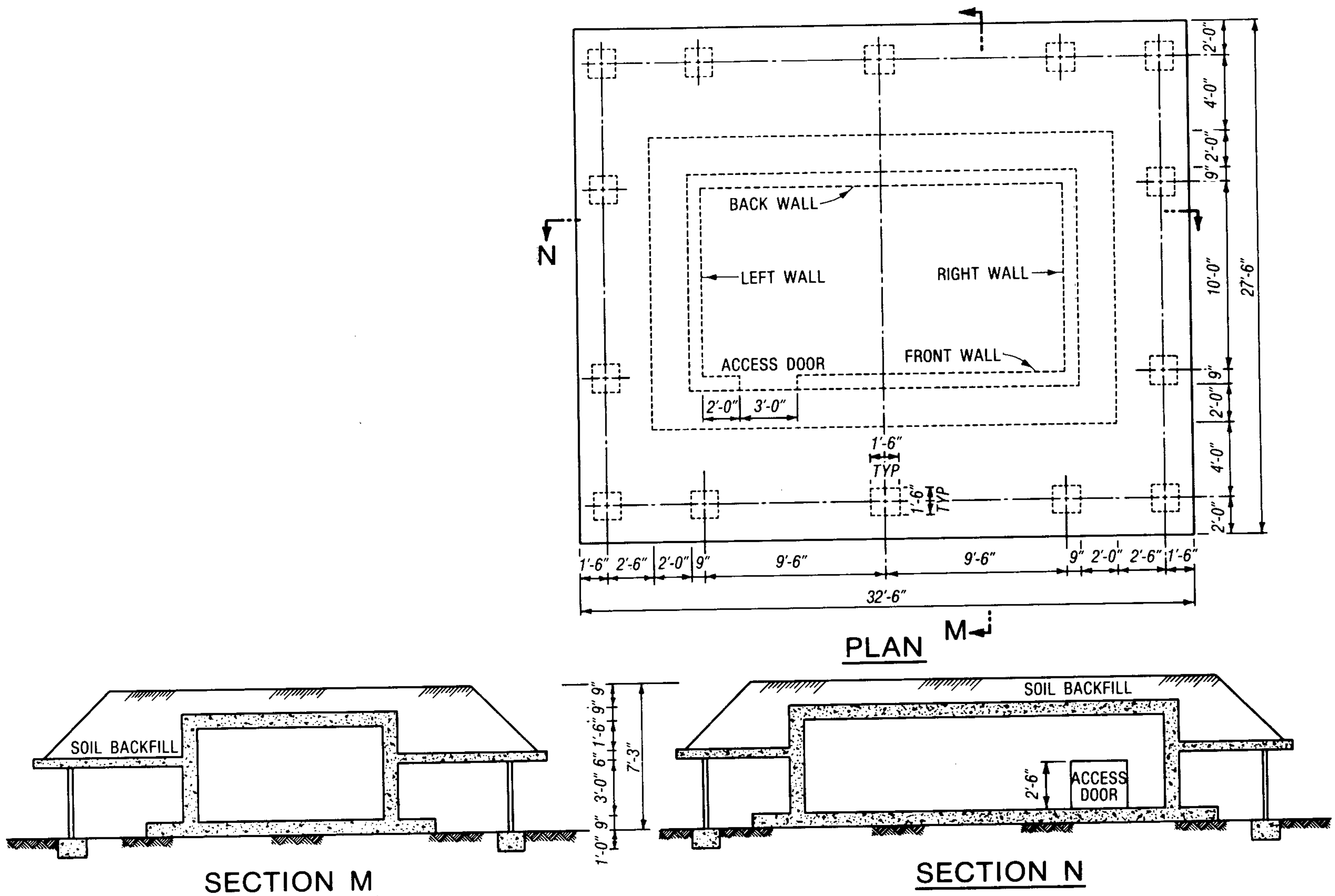


Figure 1. Layout and dimensions of maintenance bay model

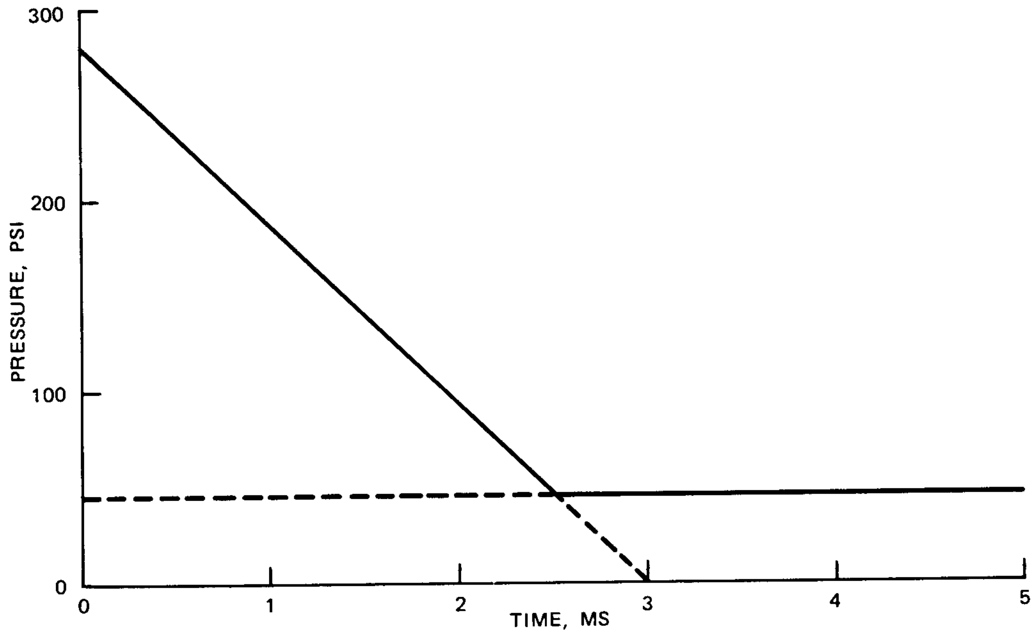


Figure 2. Pressure-time history on end wall of maintenance bay

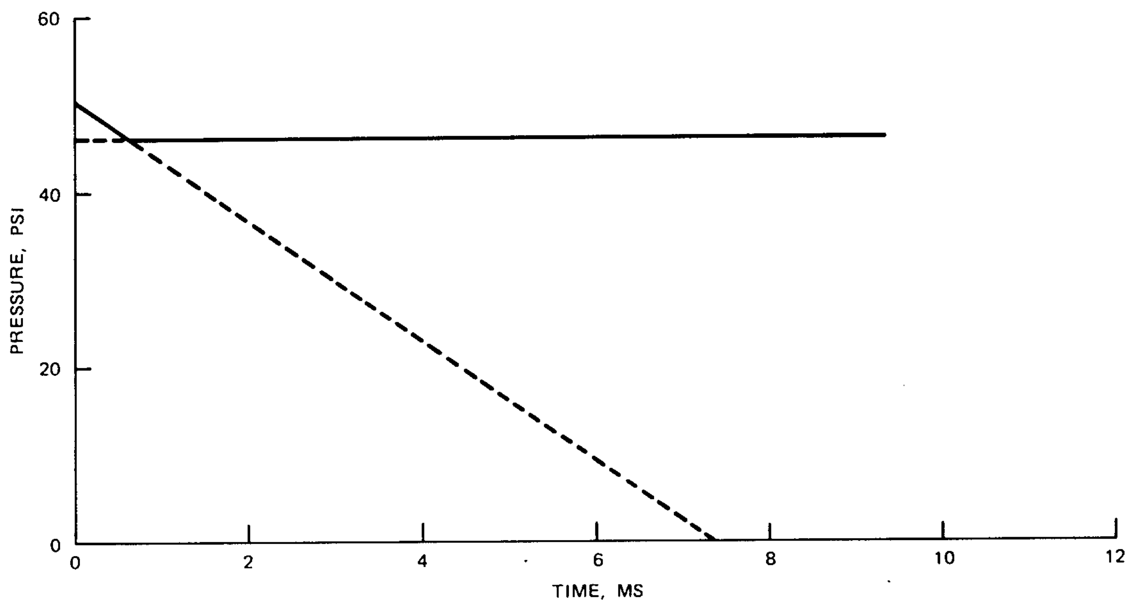
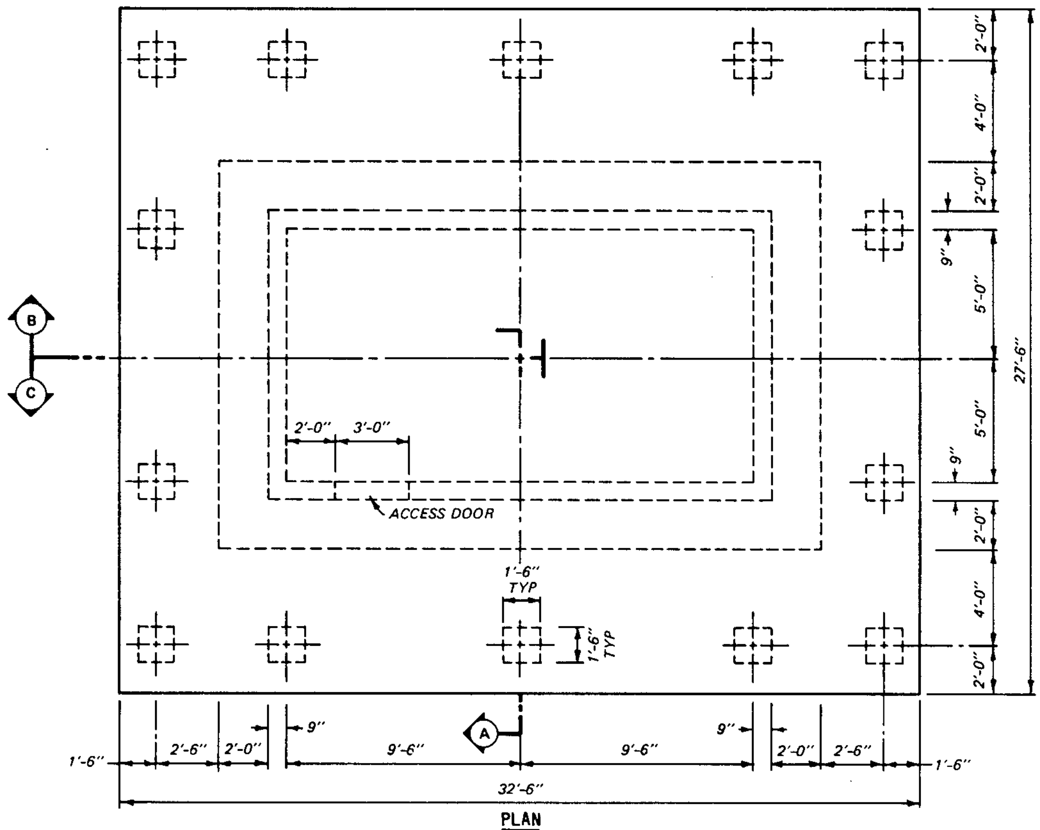


Figure 3. Pressure-time history on roof of maintenance bay



NOTES

1. UNLESS OTHERWISE NOTED, TOLERANCE ON ALL DIMENSIONS STATED IN FEET IS + 1/4"; DIMENSIONS STATED IN INCHES IS + 1/8"
2. CONCRETE CYLINDER IS 6" DIAM x 12" HT AT 28 DAYS STRENGTH, F'_c, > 4,000 PSI.
3. ALL STEEL WIRES AND REBARS WILL BE ASTM A 615-58, GR 60, YIELD STRENGTH, Fv, > 60.000 PSI; ULTIMATE STRENGTH, Fu, > 72,000 PSI UNLESS NOTED OTHERWISE.
4. CONCRETE COVER FOR PRINCIPAL REINFORCEMENT IS 1/2".
5. DIMENSIONS GIVEN ARE OUT TO OUTSIDE OF SURFACES.
6. LAP SPLICES OF REINFORCEMENT AND STEEL WIRE SHALL BE MADE ONLY AS REQUIRED USING CLASS C SPLICE.

MIN LENGTH	TENSION	COMPRESSION
NO. 4	21"	16"
NO. 3	16"	12"
NO. 2	12"	9"
0.195" DIAM	9"	6"

ABBREVIATIONS

H = HORIZONTAL
V = VERTICAL
C = CENTER
L = LENGTH
T = TOP
B = BOTTOM
EF = EACH FACE
EW = EACH WAY
JT = JOINT
INT = INTERIOR
EXT = EXTERIOR
TYP = TYPICAL
C/C = CENTER TO CENTER

Figure 4. Detailed design drawings of maintenance bay model (Sheet 1 of 6)

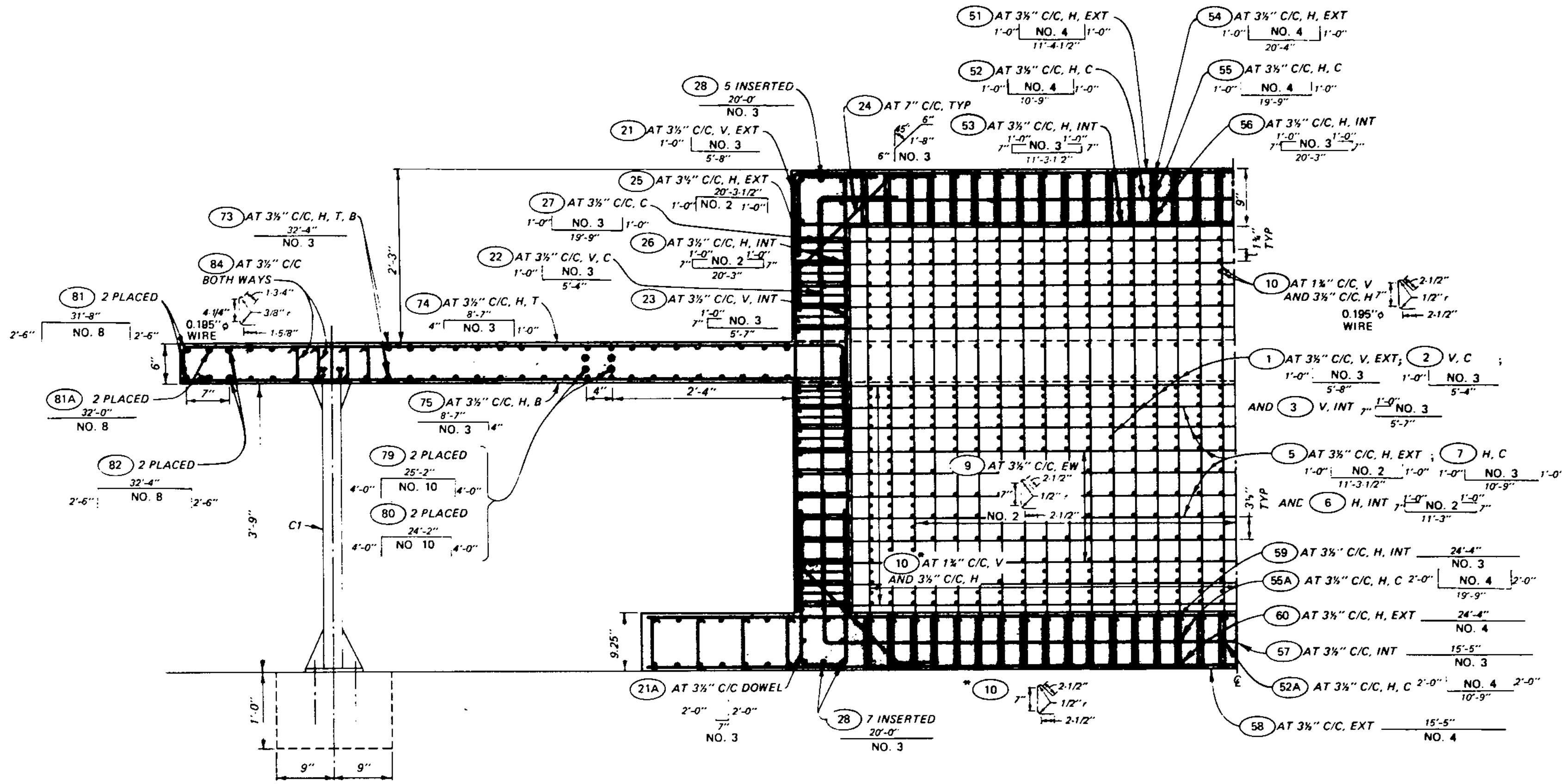


Figure 4. Section A (Sheet 2 of 6)

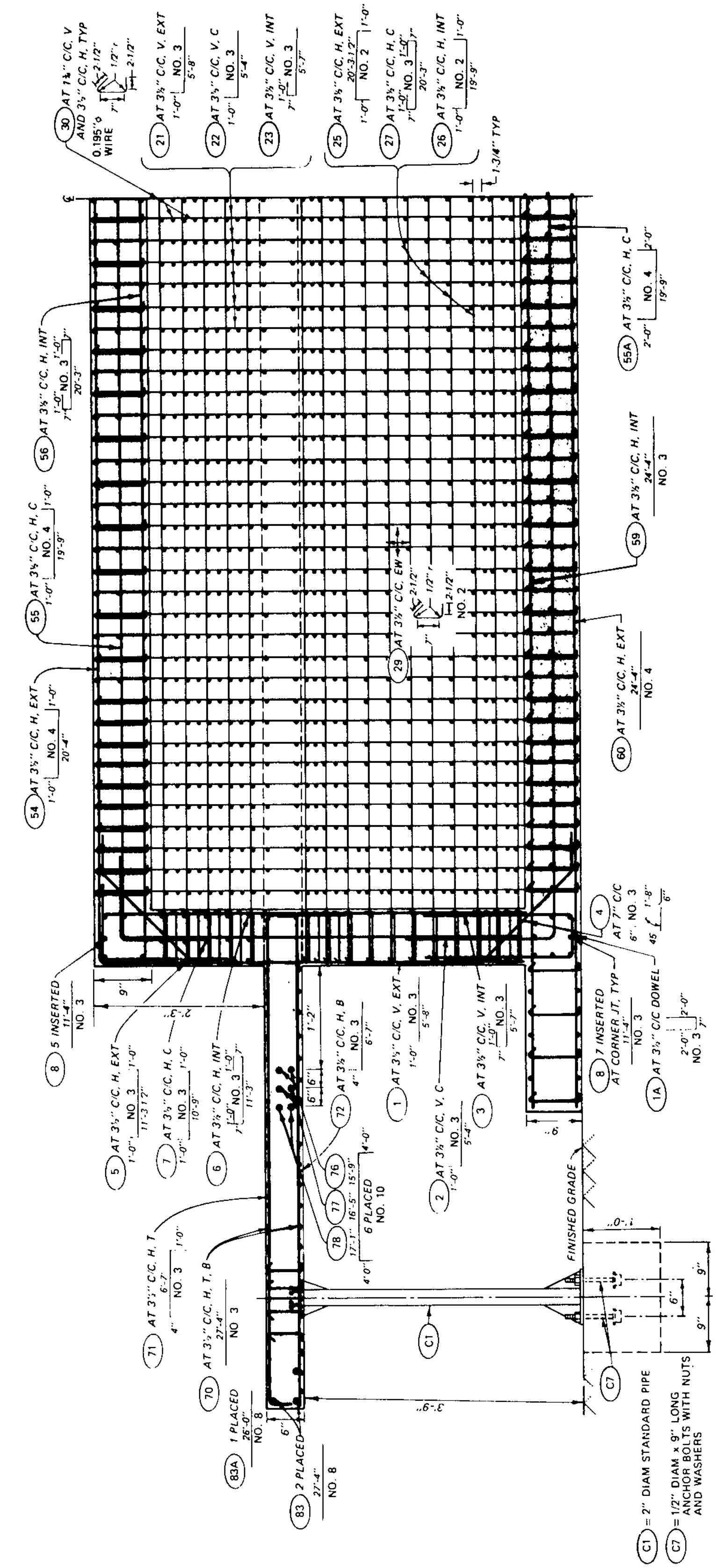


Figure 4. Section B (Sheet 3 of 6)

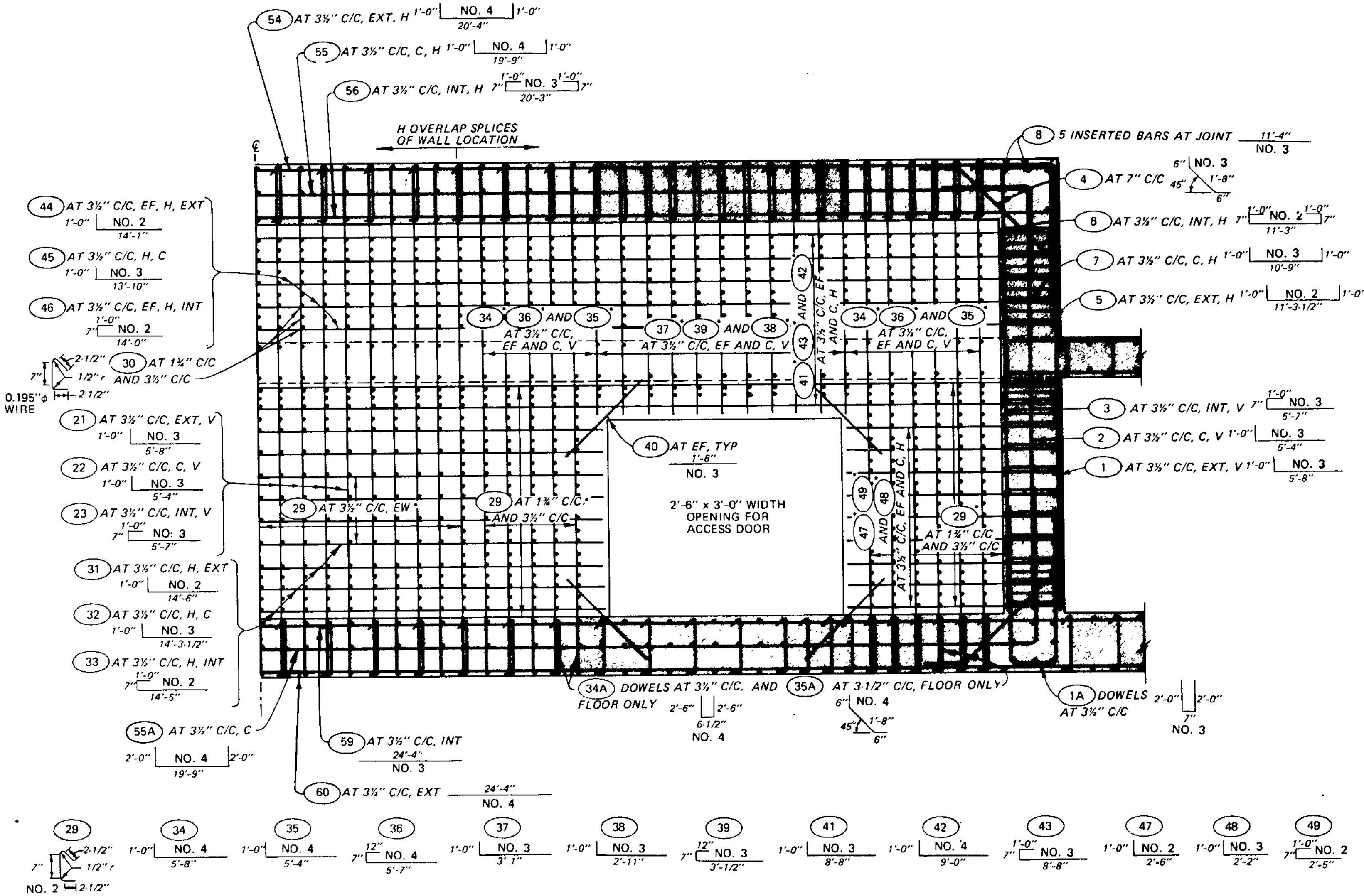
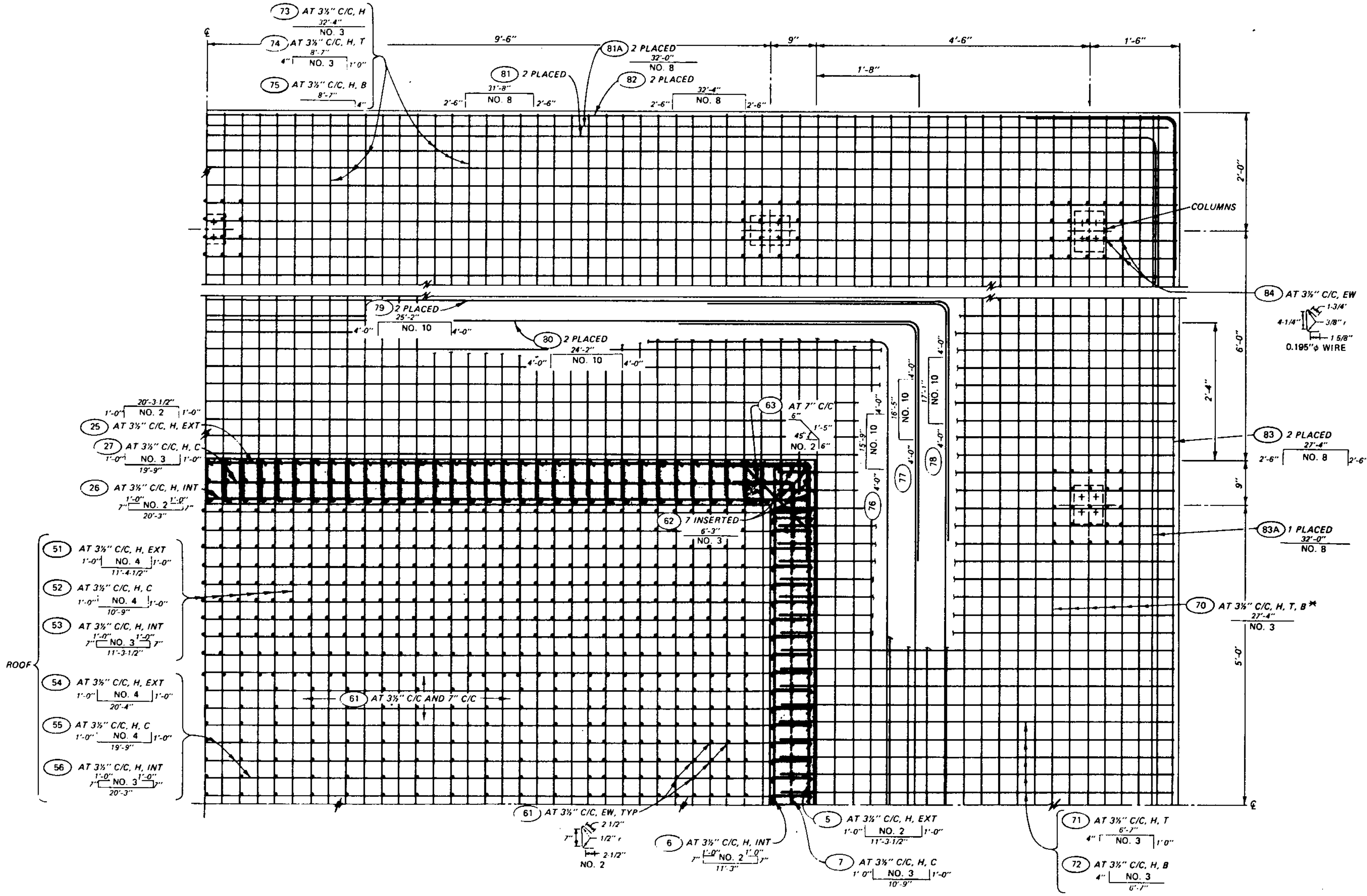


Figure 4. Section C (Sheet 4 of 6)



* IN THE TOP LAYER OF THESE BARS GRADE 40 STEEL WAS USED. THESE BARS WERE 20 FT LONG AND WERE LAPPED SO THAT THE LAP WOULD BE AS FAR FROM THE TEST CHARGE LOCATION AS POSSIBLE.

Figure 4. One-quarter plan view of roof, walls, and collar (Sheet 5 of 6)

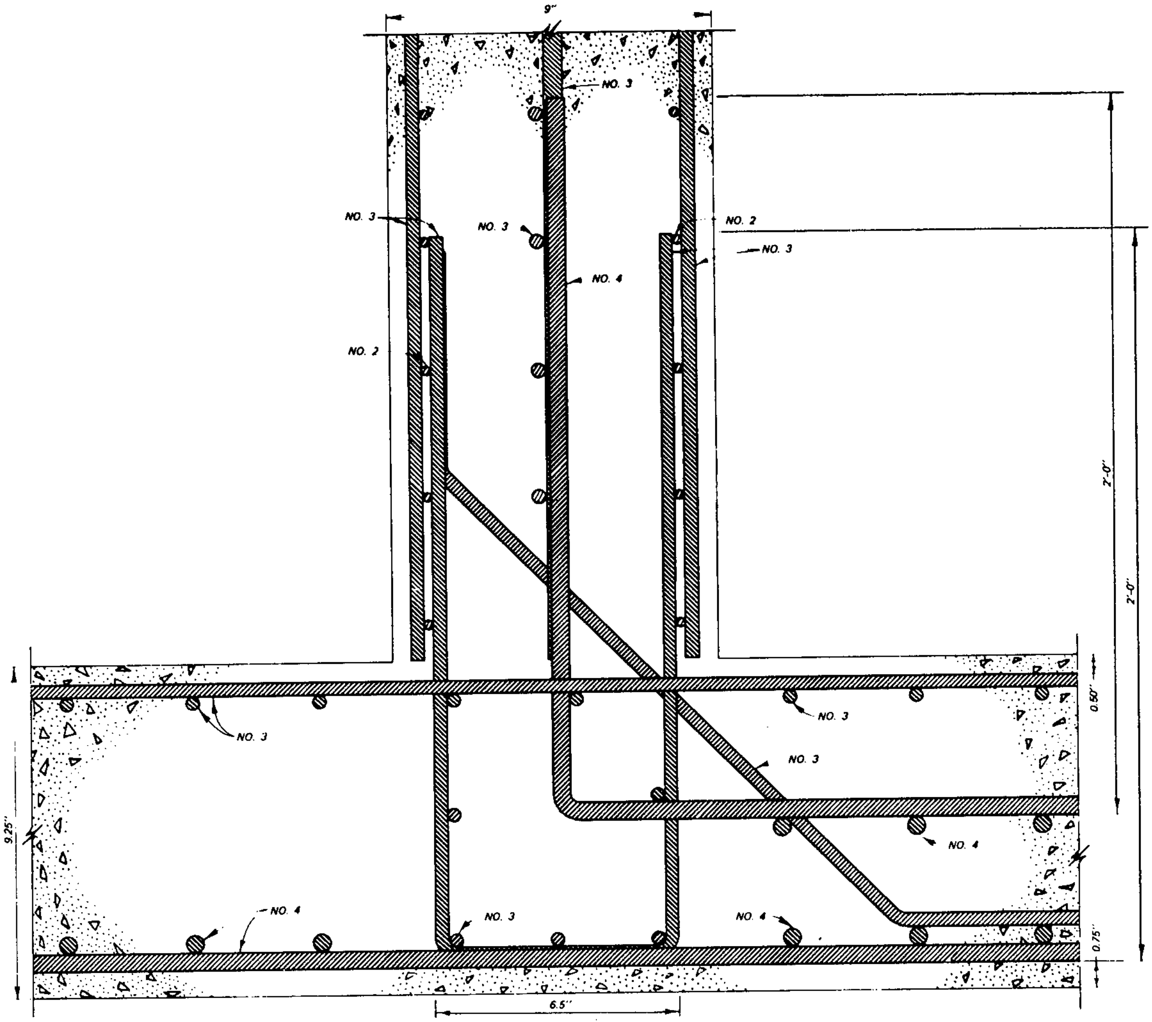


Figure 4. Elevation view, typical intersecting floor slab and wall detail (Sheet 6 of 6)

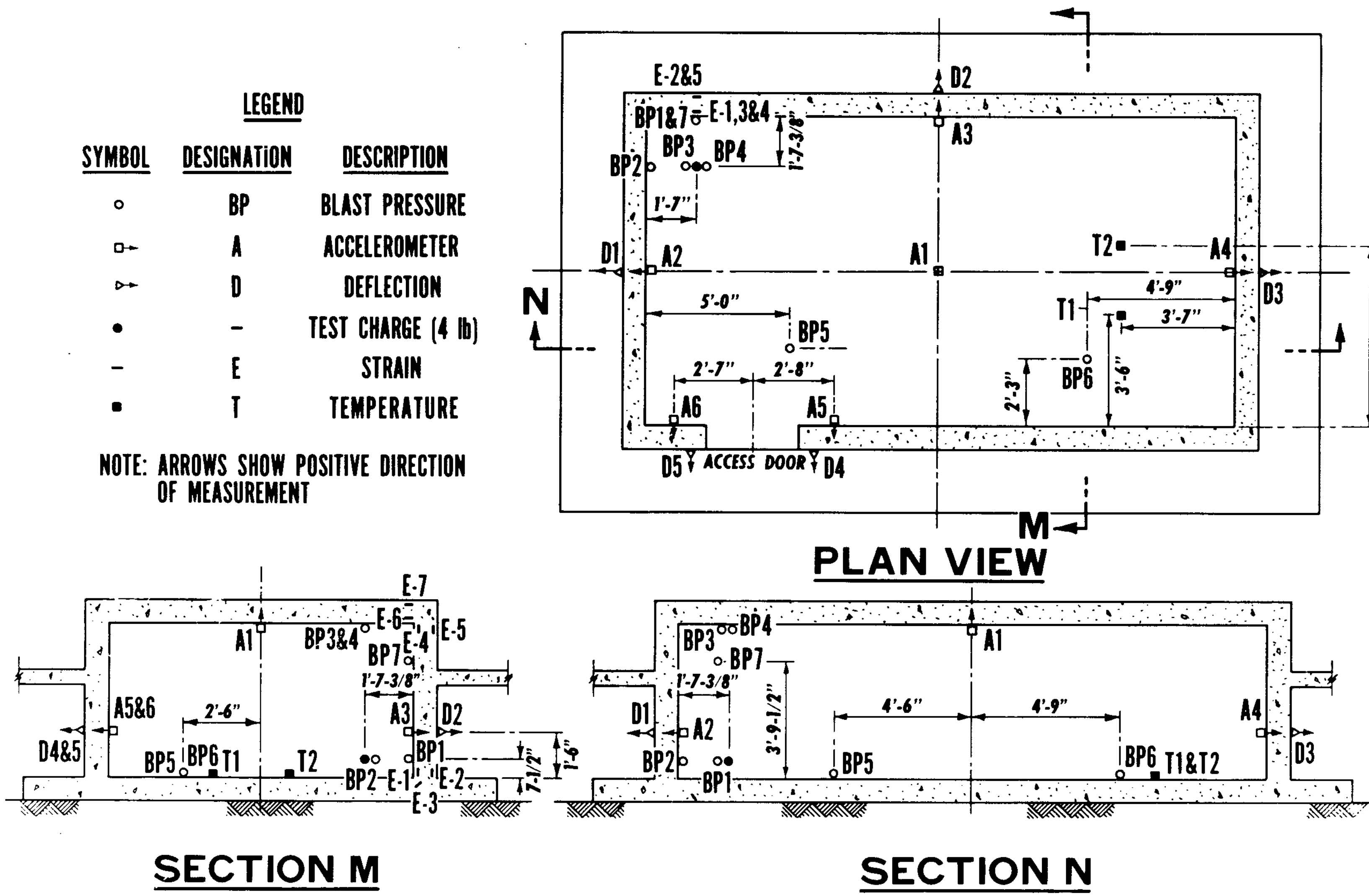


Figure 5. Maintenance bay instrumentation layout, Test 1

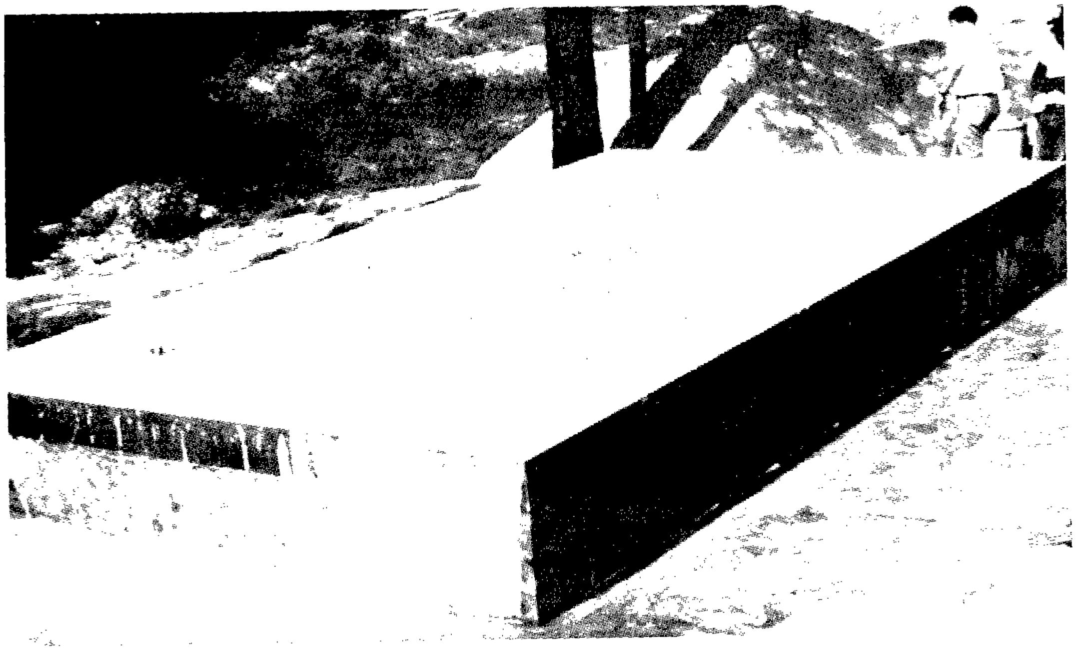


Figure 6. Bubbles from soapy water revealed cracks in roof after Test 1

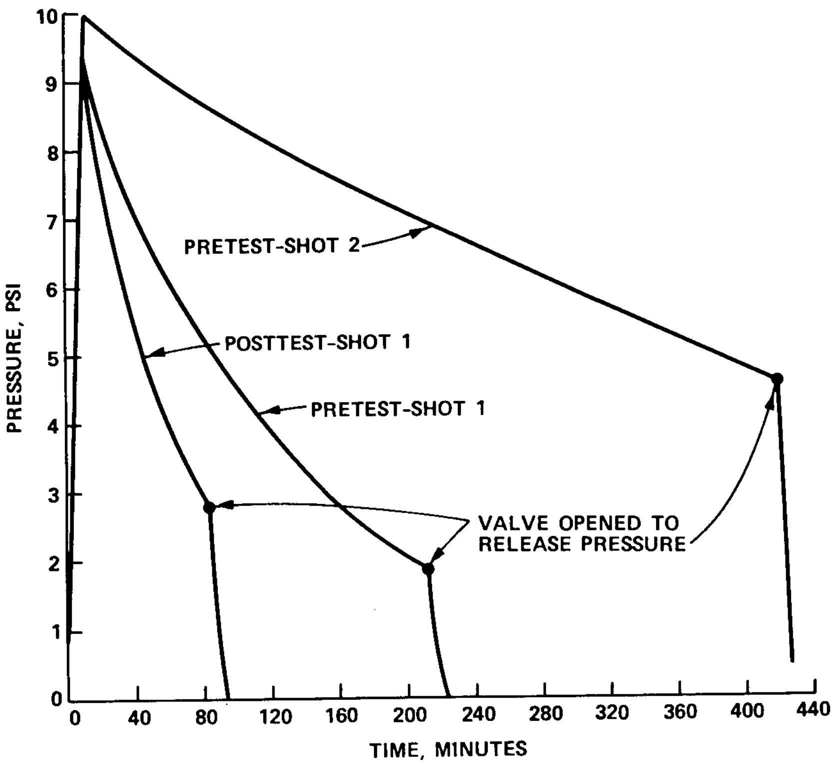


Figure 7. Maintenance bay static pressure test results

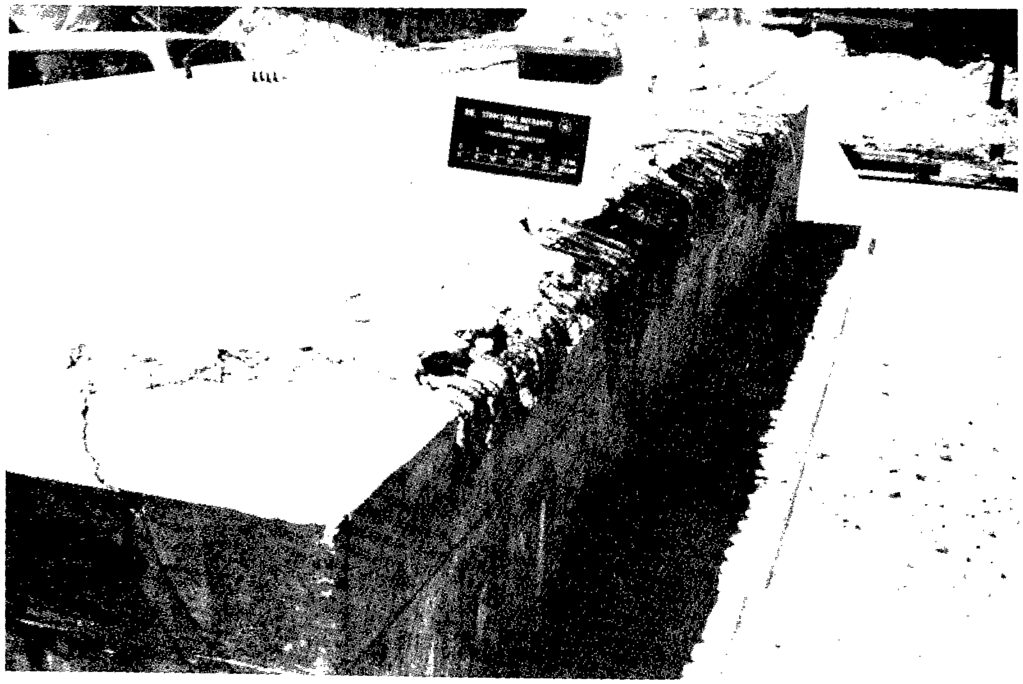


Figure 8. Outside view of damaged roof after Test 2. Note damage at edge of roof and crack in concrete at corner

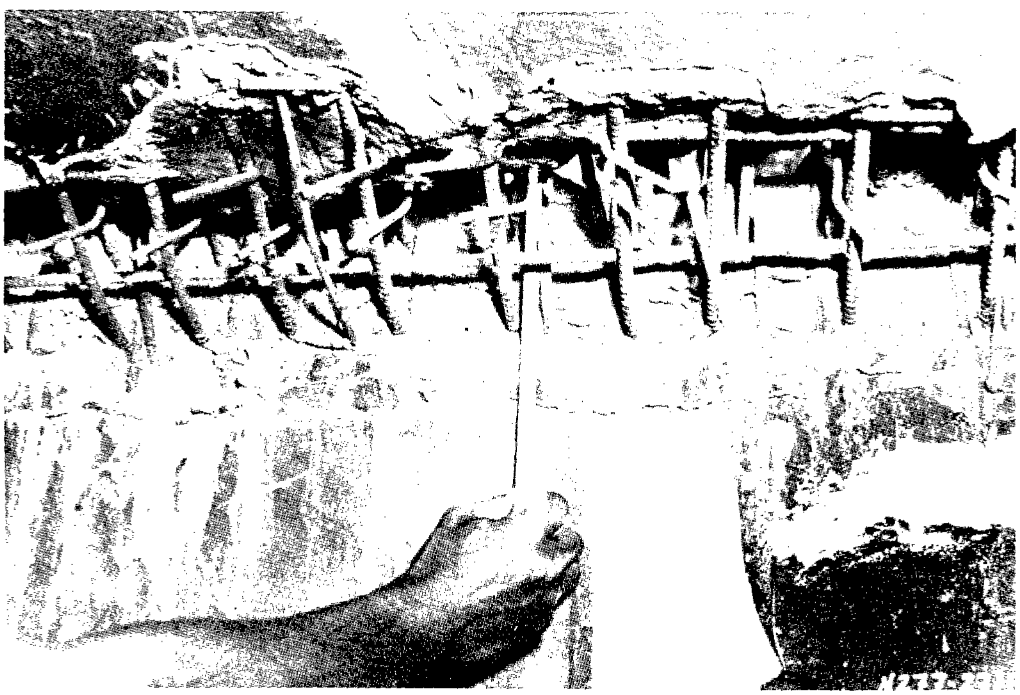


Figure 9. Interior view of roof edge following sealant and loose concrete removed after Test 2

FRAGMENT HAZARD INVESTIGATION PROGRAM

QD CRITERIA FOR 155MM PROJECTILES

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INTRODUCTION

The Department of Defense Explosives Safety Board (DDESB) is conducting a continuing program to evaluate the fragment hazards produced by the accidental detonation of stored munitions. In support of this effort, the Naval Surface Weapons Center was funded to conduct the Fragment Hazard Investigation Program. The purpose of the program is to provide the DDESB with fragmentation data to improve or to substantiate the quantity-distance (QD) standards for the safe and efficient storage of stacked munitions. The current program uses near-field fragment characterization data in conjunction with far-field collection data to predict far-field fragment density. The ultimate goal is to provide a methodology for the determination of QD standards for all hazard classifications. The hazard classification under investigation in this paper is the Mass-Detonating Hazard Materials (Class 1, Division 1).

The major effort of this program to date has been focused on the mass-detonating Army M107 155mm (TNT loaded) projectile. Close-in arena and far-field collection tests of various projectile and pallet stacking configurations have been conducted concurrent with supporting analytical studies. Fragmentation data were generated on projectile clusters which simultaneously detonate[1 2] and on those which detonate by means of natural communication.[3] Far-field collection tests were conducted on large stacks (up to 36 pallets) of projectiles at the White Sands Missile Range.[4] A methodology was developed based on the entire set of test data which accurately predicted the total far-field fragment density. However, the assumptions used to develop the methodology were found to limit its usefulness in calculating the hazardous portion

[1]Ramsey, R. T., et al, "Fragment Hazard Investigation Program", Minutes of 18th DOD explosives Safety Board Seminar, September 1978.

[2]Ramsey, R. T., et al, "Fragment Hazard Investigation Program", NSWC Technical Report, TR-3664, October 1978.

[3]Powell, J. G., et al, "Fragment Hazard Investigation Program (Large-Scale Detonation Tests", Minutes of 19th DOD Explosives Safety Board Seminar, September 1980.

[4]Powell, J. G., et al, "Fragment Hazard Investigation Program Natural Communication Detonation of 155mm Projectiles", NSWC Technical Report TR 81-54, July 1981.

of the far-field distribution. This limitation was overcome by the development of a fragmentation computer model[5] which uses the fragmentation characteristics obtained from arena tests to predict far-field fragment hazards.

This paper presents the results of the test and analysis effort accomplished to validate the computer model for pallets of 155mm projectiles.

MODEL VALIDATION

Test Program

Review of the fragmentationdata developed on single pallets of projectiles and the large-scale multiple pallet detonation tests conducted at WSMR indicated that additional small-scale fragmentation arenas were required. These tests consisted of the detonation by means of natural communication of two pallets of projectiles. The projectiles were positioned horizontally as shown in Figure 1. The velocity and presented area of all fragments weighing more than 300 grains were obtained between polar angles 0°-110°.

Prediction of Far-Field Fragment Density

The computer model and the two pallet tests data were used to generate predictions of the total far-field fragment density for the 16 pallet and 36 pallet stack configurations tested at WSMR. Figures 2 and 3 present a comparison of the minimum and maximum fragment density predicted by the model (20 replications) and the test data for three 10° collection zones. The plots show that the model adequately bounds the test data for both stack configurations. This indicates that the model and the small-scale arena data can be used to generateQD criteria for stacks of 155mm projectiles.

QD CRITERIA

The computer model calculates the QD curve based upon hazard criteria provided as input.[5] The curve is presented as the number of projectiles required in the stack face to just exceed the established criteria. Figure 4 presents the QD curve for 155mm projectiles using the current DDESB definition of one hazardous fragment (kinetic energy = 58 ft lb) per 600 sq ft. Shown for comparison is the current Class 1 Division 1 QD criteria (40 $W_{EX}^{1/3}$) for the 16 pallet and 36 pallet tests at WSMR. It can be seen that the computer model indicates that the current criteria underestimates the fragment hazard for munitions stored in the open.

[5] McCleskey, F. R., "Fragmentation Hazard Computer Model", Minutes of 21st DOD Explosives Safety Board Seminar, August 1984.

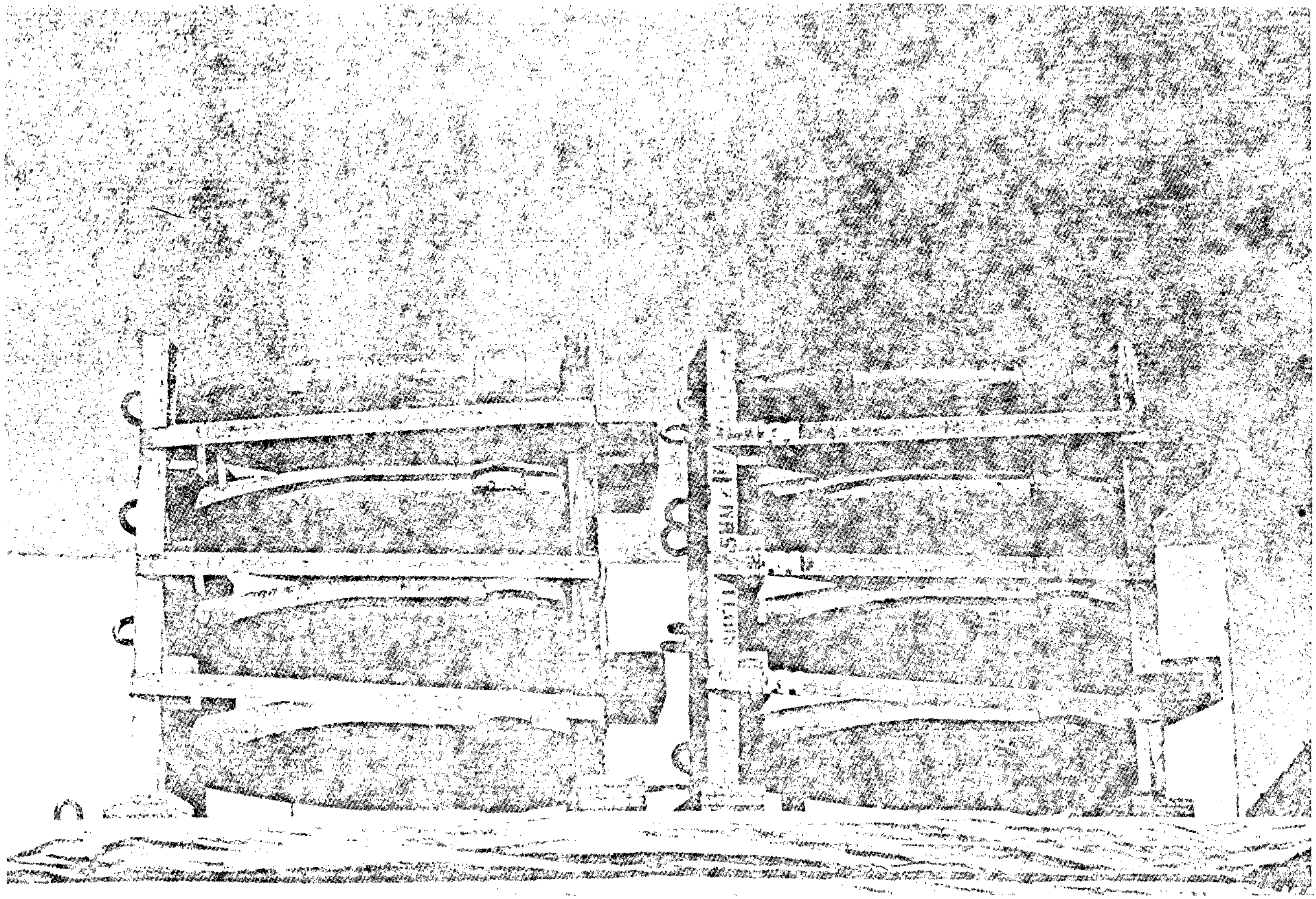
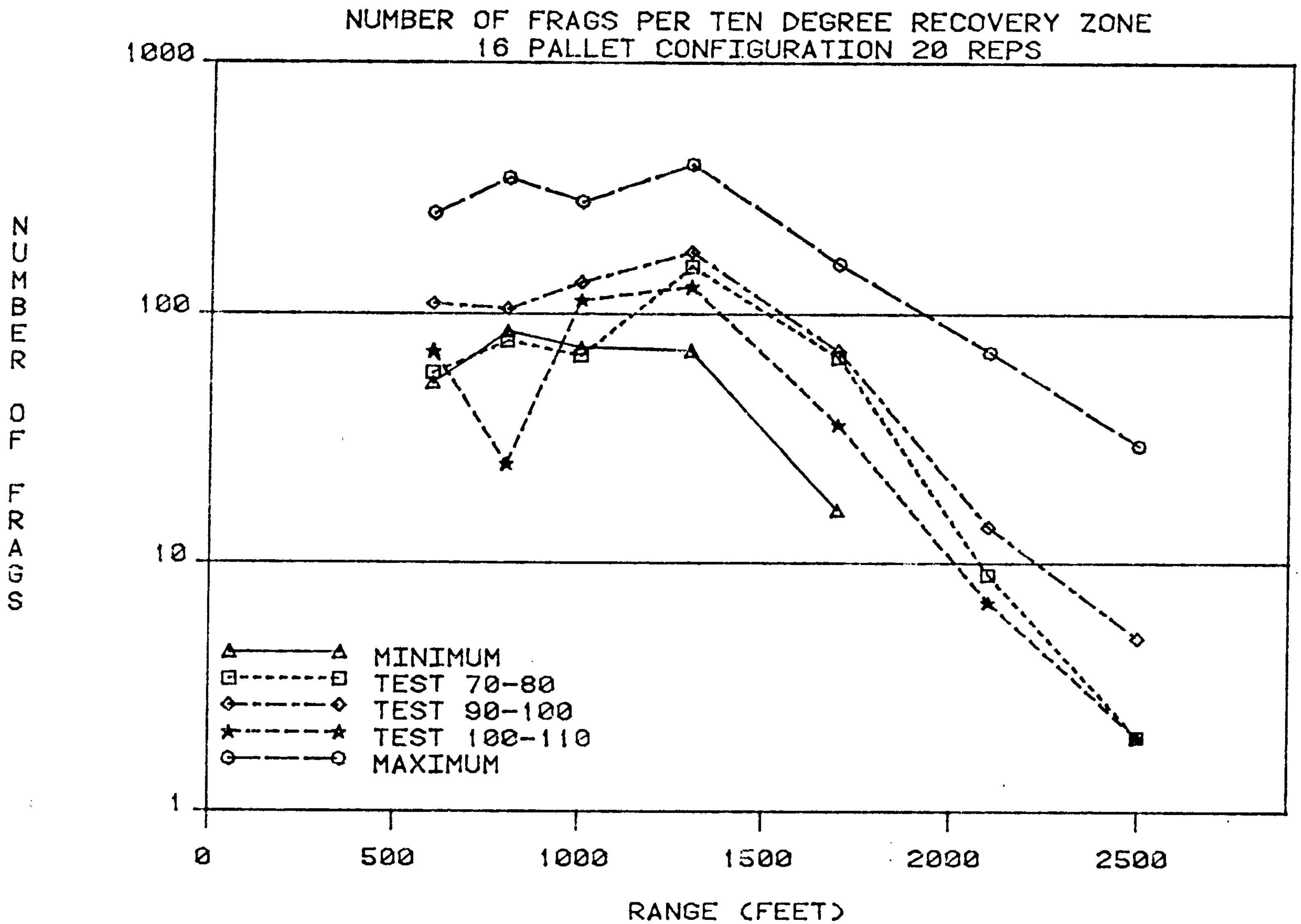


Figure 1

Two Pallet Test Configuration For Small-Scale Fragmentation Arenas



NUMBER OF FRAGS PER TEN DEGREE RECOVERY ZONE
16 PALLET CONFIGURATION 20 REPS
NUMBER OF FRAGS
1000
100
10
1
0
500
1000
1500
2000
2500
RANGE (FEET)
MINIMUM
TEST 70-80
TEST 90-100
TEST 100-110
MAXIMUM

Figure 2

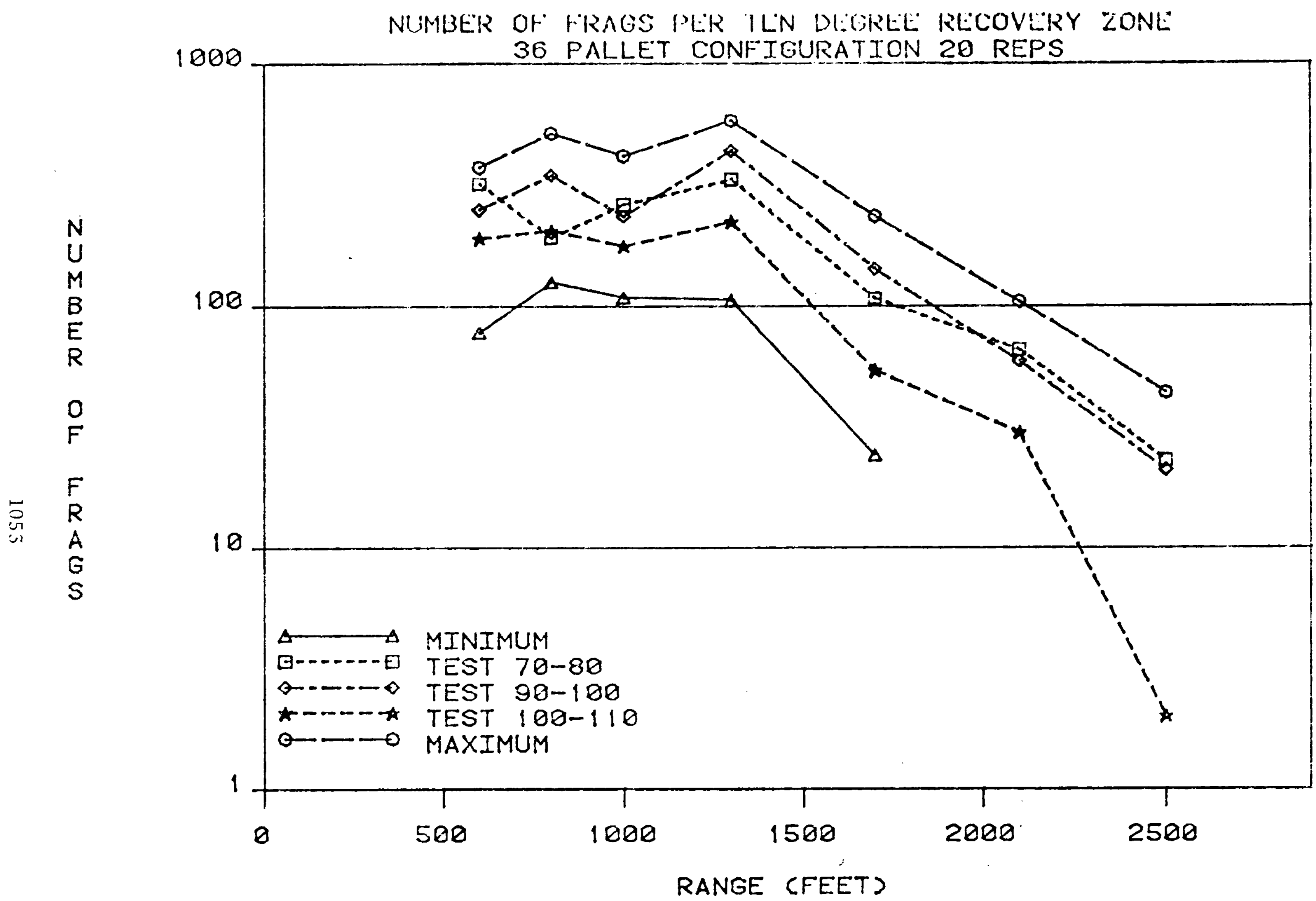

NUMBER OF FRAGS PER TEN DEGREE RECOVERY ZONE
36 PALLET CONFIGURATION 20 REPS
NUMBER OF FRAGS
1000
100
10
1
0
500
1000
1500
2000
2500
RANGE (FEET)
MINIMUM
TEST 70-80
TEST 90-100
TEST 100-110
MAXIMUM

Figure 3

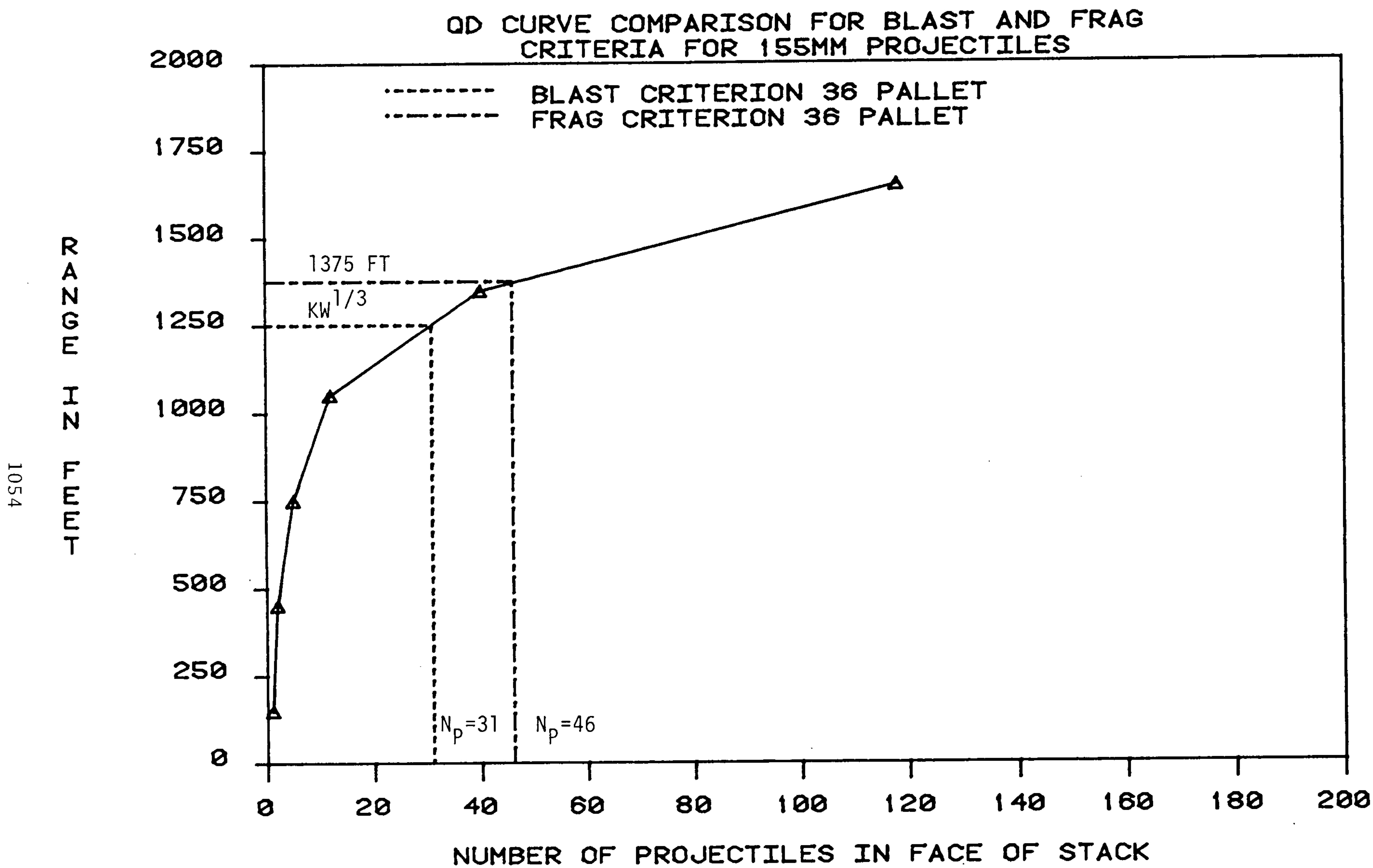

QD CURVE COMPARISON FOR BLAST AND FRAG
CRITERIA FOR 155MM PROJECTILES
BLAST CRITERION 36 PALLET
FRAG CRITERION 36 PALLET
RANGE IN FEET
2000
1750
1500
1250
1000
750
500
250
0
1375 FT
KW1/3
Np=31
Np=46
0
20
40
60
80
100
120
140
160
180
200
NUMBER OF PROJECTILES IN FACE OF STACK

FIGURE 4

CONCLUSIONS

The results of this study indicate the that the computer model is an accurate, flexible method of determining the fragment hazards for stacks of 155mm projectiles. The model will be validated for another mass-detonating munitions (general purpose bombs) and will be modified to allow the computation of fragment hazards for non-mass detonating ammunition (Class 1, Division 2) during FY 85.

FRAGMENTATION HAZARD

COMPUTER MODEL

BY

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Autovon 249-8836

Commercial 703-663-8836

This model provides a method for establishing the fragment hazard produced by the mass-detonation of ammunition stacks stored in the open. Fragmentation characteristics used as input to the model are derived from small-scale arena tests. In the case of 155mm projectiles, for example, the small-scale test may consist of one or more pallets positioned and detonated to yield a representative sample of an entire stack.

Hazardous fragmentation is defined by the Explosive Safety Board as follows:

1. Fragment kinetic energy of at least 58 ft-lbs.

2. Hazardous fragment density of at least one fragment per 600 square feet.

The hazardous fragment density criterion is equivalent to a hit probability of .01 given that the presented area of a man is six square feet.

The unique feature of the model lies in the fact that a complete trajectory is calculated for each fragment recovered in the small-scale arena tests. This procedure requires a great amount of calculations which are made practical by modern high speed computers.

Past tests have demonstrated that virtually all the fragmentation going down-range is produced by the ordnance (projectiles, bombs, etc.) on the face of the stack pointing toward the target area. Fragmentation from the ordnance in the interior of the stack is, for the most part, contained within the stack. When a stack is detonated, fragment jets are produced between adjacent items on the face of the stack. The width of the jet is dependent on the method of stack initiation. When all units are detonated simultaneously, the jet is typically 10 degrees wide. If only one or two donor units are initially detonated, the jet width is more typically 20 degrees. Stack detonation by donor units is called natural communication and all current testing uses this technique.

The jets produced between adjacent units are called interaction areas. The greatest fragment densities and highest velocities are produced within the interaction areas. For safety purposes, the fragmentation characteristics of the

interaction areas are used for input to the computer model. The interaction areas overlap at relatively short distances down-range and their effects can therefore be added to represent the cumulative effect of large ammunition stacks.

Figure 1 shows the essential elements of the model. Since interaction areas overlap at relatively short distances down-range, all fragments are assumed to emanate from a vertical line at the center of the stack. The height of the vertical line is made consistent with the typical stack height of the ordnance under consideration. The height at which an individual fragment originates is randomly selected within the program. A pie-shaped sector is used to simulate the down-range hazard volume. A hazardous fragment is only of concern when its trajectory lies within this pie-shaped hazard volume. The height of the sector is equal to the height of the man selected. The angular width of the sector is 10 degrees. This value has been selected to match the 10 degree sector width used in the fragment pickup from full-scale tests. In this way, one can compare the program predictions with actual test data to gauge the validity of the simulation model. The sector is divided into 100 feet segments from 0 to 4800 feet. All calculations of fragment numbers, fragment density, etc. are made in terms of these 100-feet segments. Later in the simulation, the results in each 100-feet segment may be combined to yield results for 200, 300 and 400 feet increments. This helps to produce smooth curves for final plotting. If results are plotted every 100 feet, a pronounced saw-toothed plot is usually produced.

Figure 2 shows a more detailed picture of a fragment trajectory. Wind is included as a two dimensional velocity vector having both a range and cross-range component. There is no vertical component to the wind vector. The wind, therfore, is always contained in a horizontal plane. The vertical position for the origin of the fragment trajectory is selected randomly from a range of heights typical of the stack heights for the ordnance under consideration. The trajectory is calculated using a fourth-order Runge-Kutta routine. Calculations are made in three dimensions with the effects of wind included. The Runge-Kutta routine requires initial conditions for fragment velocity and elevation angle which are obtained from fragment arena tests. Each point in the trajectory is calculated from the conditions existing at the previous point. The calculations continue until impact; at which time, the impact velocity and angle are determined. The impact velocity, together with the known fragment mass, are used to determine the kinetic energy. The impact kinetic energy is compared with a kinetic energy criterion to determine whether the fragment is hazardous. The impact angle is used in subsequent density and probability of hit calculations. Range, cross-range and distance are computed for hazard distance calculations. Currently, the initial fragment velocity vector is constrained to the vertical XY plane. However, since the model uses a true three dimensinal routine, there is complete three dimensional freedom for establishing initial conditions. Trajectory calculations are made for each fragment recovered in the small-scale test.

A tailwind has three effects on hazard conditions--all bad. First, a tail-wind will increase the range of the fragments. Second, it will increase the impact velocity of the fragments thereby increasing their lethality. Third, a

tailwind will decrease the angle of impact thereby increasing the presented area of the man which increases the probability of hit. The increased range due to a tailwind is approximately equal to the time of flight multiplied by the wind speed. In the far range where the time of flight is approximately 10 seconds, a tailwind speed of 50 feet per second will result in a range increase of about 500 feet.

Figure 3 shows the two types of trajectories considered in the model. The normal, or non-ricochet, trajectory has been considered above. The ricochet trajectory is a more recent addition to the model. It is based on experiments conducted by BRL, Aberdeen in the late 1960's (reference 1). In both types of trajectories, the points at which the fragment enters and leaves the hazard volume are accurately calculated. This permits the hazard to be definitely associated with the proper distance increment. When a fragment impacts the ground, its impact angle is compared with a critical ricochet angle to determine whether the fragment will ricochet. The critical ricochet angle is dependent on the type of soil. Once it is determined that the fragment will ricochet, the ricochet angle and velocity are determined from the incident angle and velocity together with the effect of the soil type. Since all the dynamic characteristics of the fragment are known at each point calculated in the Runge-Kutta routine, all fragment hazard characteristics can be calculated at each point. When more than one point is contained in a distance increment, averages are used to determine the hazard characteristics for the distance increment.

Figure 4 shows how hazard density and hazard probability of hit are calculated. Since the trajectories are calculated point by point, the distance increment of the hazard volume through which the fragment passes can be determined. The fragment mass and velocity are known at each point and, therefore, it can be determined whether the fragment possesses sufficient kinetic energy to exceed the hazardous kinetic energy criterion. After the fragment has been determined to be hazardous, the presented areas of the man and of the total volume of the distance increment can be calculated in the plane perpendicular to the fragment trajectory. This can be done because the trajectory angle with respects to the horizontal plane is calculated at each point along the trajectory. Once the presented areas of the man and of the total volume of the distance increment are known, the density and probability of hit can be calculated using the formulas shown on Figure 4. The number of hazardous fragments (N_f) is based on the data from arena tests using appropriate scaling techniques. Note that the man is depicted as a rectangular parallelepiped.

The model is run as a Monte Carlo program. Simply stated, this means that the values for certain variables are randomly selected for each trajectory calculation. The five variables which are randomly selected are:

1. Height of the trajectory origin

2. Initial fragment velocity

3. Initial fragment elevation angle

4. Drag coefficient

5. Soil constant for ricochet

The random values are selected within the known or assumed ranges of uncertainty for each variable. Once the appropriate values have been selected for the variables, trajectories are calculated for the entire set of fragments recovered from the small-scale arena test. The entire procedure is repeated (replicated) using different random values for the variables. In effect, each replication is a simulation of a full-scale test. The values of the output variables vary from replication to replication because of the random values used for the input variables for each replication. During each replication, data are saved for hazard calculations as a function of distance increments. In the program, 100 feet distance increments are used. Sufficient replications are made to permit density and probability of hit to settle near stable averages. Once these near stable averages are obtained, the number of rounds needed to just exceed the density and probability of hit criteria are calculated as a function of distance increment. These are the final data to be used in establishing the fragment hazard posed by the ammunition under consideration. The model includes methods for presenting the data at 100, 200, 300 and 400 feet distance increments. One of these increments will usuually produce relatively smooth data for plotting. With a 100 feet increment, the final data are usually quite saw-toothed. Since the model includes the effects of wind, the program can be run at various wind speeds, and the effect of wind noted.

Table 1 shows typical fragmentation input data. Each fragment recovered from the arena test has its own set of data. Usually all fragments less than 300 grains are eliminated. The small fragments are of little concern for the far ranges which are of most importance in establishing fragment hazards. The recovery polar zone is listed for each fragment. In the program, an angle is randomly selected between the polar zone limits to establish a distinct elevation angle for the fragment. The fragment weight is an exact number for each fragment and is not randomized. The initial velocity is an average for the polar zone in question. A random velocity about the average is picked to account for the uncertainty in velocity measurement. The A/M (average presented area to mass ratio) is an exact number for each fragment. This quantity enters the drag calculations. The area ratio (maximum to minimum fragment presented area) is used to establish the subsonic drag coefficient. The use of this ratio eliminates about one quarter of the uncertainty associated with the subsonic drag coefficient. Transonic and supersonic drag coefficients are established form the subsonic drag coefficient.

There are two basic outputs: Number of Final Ground Impacts versus Distance Increment and Hazard Distance versus Number of Rounds.

Table 2 shows the Number of Final Groud Impacts versus Distance Increment. Values for the minimum, average and maximum number of fragments are shown for each distance increment. The data apply to a 10 degree azimuth sector which is often used in the fragment pickup from full-scale tests. The data in Table 2 are used to compare the predicted and actual number of fragments picked up in the full-scale tests. This provides a check on the validity of the model. Each replication of the program will usually produce a different number of final ground impacts. After all replications are completed, the minimum, average and maximum numbers can be determined.

Table 3 shows the final output used to establish the hazard curves. The example shows a distance increment of 200 feet. The hazard distances are selected at the midpoints of the hazard increments so that the data are ready for plotting. Minimum, 90th percentile, average and maximum number of units required are shown. These numbers represent the required number of projectiles needed to just exceed a hazard density of one fragment per 600 square feet. The Explosive Safety Board currently specifies the use of 90th percentile quantities for hazard curves. The 999999 entries indicate that there were no hazardous fragments in the distance increment. The fewer the number of projectiles required, the more hazardous the condition. A similar table is also output for the hazardous probability of hit criterion.

Figure 5 shows an example plot of the final data for use in a safety manual. Note the steep rise and subsequent asymtotic behavior. Unlike hazardous blast radii, the fragmentation hazardous distance has an upper bound. This upper bound is equal to maximum fragment range obtained in the series of replications. No matter how many projectiles are on the face of the stack, the maximum range of the fragments constrains the upper bound.

The computer model provides a flexible tool for predicting the fragment hazards of open storage ammunition. Unlike analytical approaches, the Monte Carlo technique has the inherent capability of considering the multidimensional problem posed by fragmentation hazards. Future considerations are also more easily incorporated in a Monte Carlo model. In summary, the essential characterstics of the model are as follows:

- Individual 3-D fragment trajectories
- 2-D wind (horizontal plane)
- 4th order Runge-Kutta trajectory calculations
- Incorporates a 3-D man
- Can use different hazard criteria
- Air density and sound speed a function of altitude
- Drag coefficient a function of the maximum to minimum fragment area ratio
- Predicts distribution of final impacts in the ground plane
- Predicts hazard distance curves for:

    Hazard density criterion

    Hazard probability of hit criterion
- Includes fragment ricochet

Reference

1. Fragment Ricochet Off Homogeneous Soils and Its Effects on Weapon Lethality (U), Mark Reches, Army Material Systems Analysis Agency Technical Memorandum No. 79, August 1970, CONFIDENTIAL

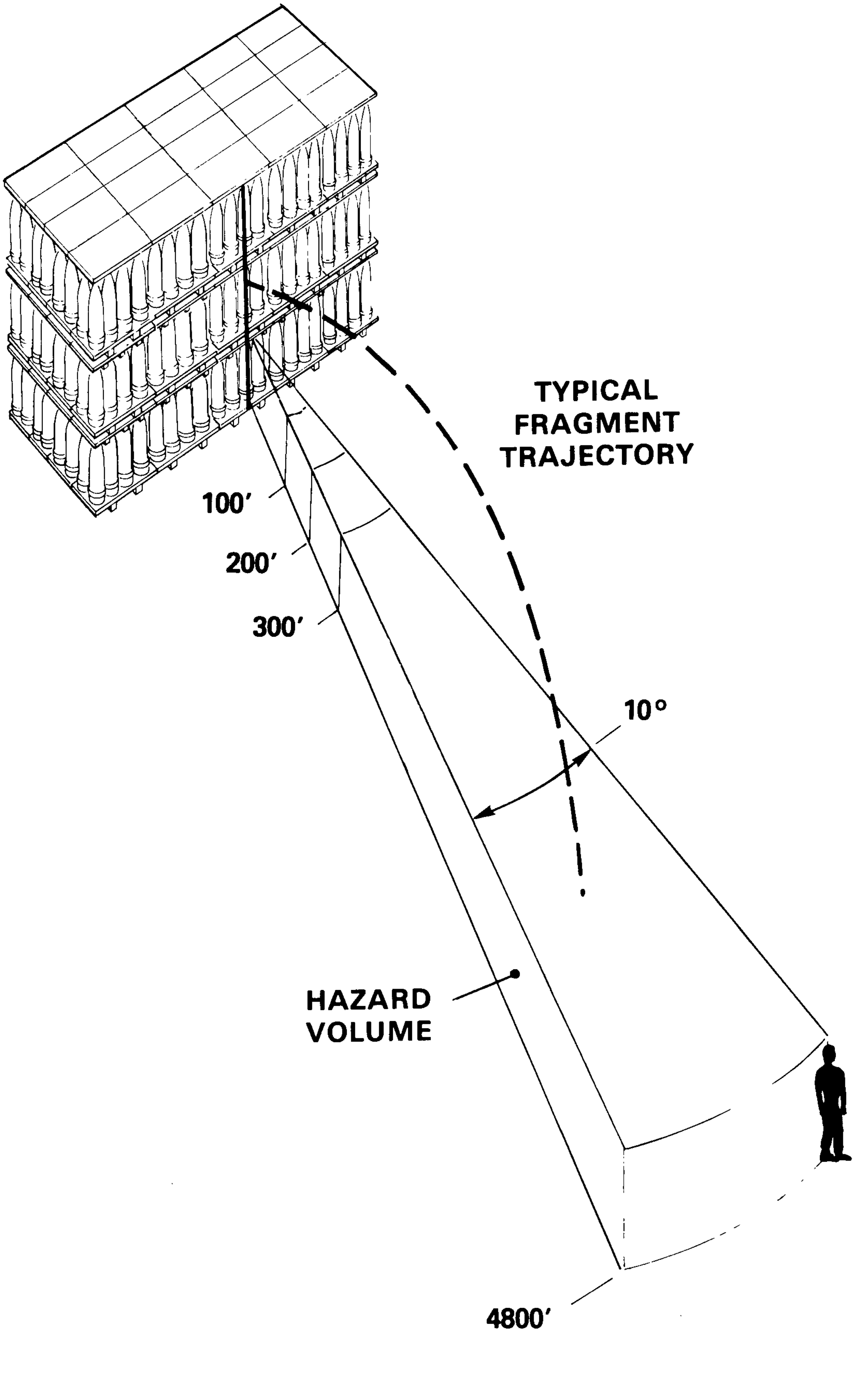


FIG 1 — STACK FRAGMENTATION SIMULATION

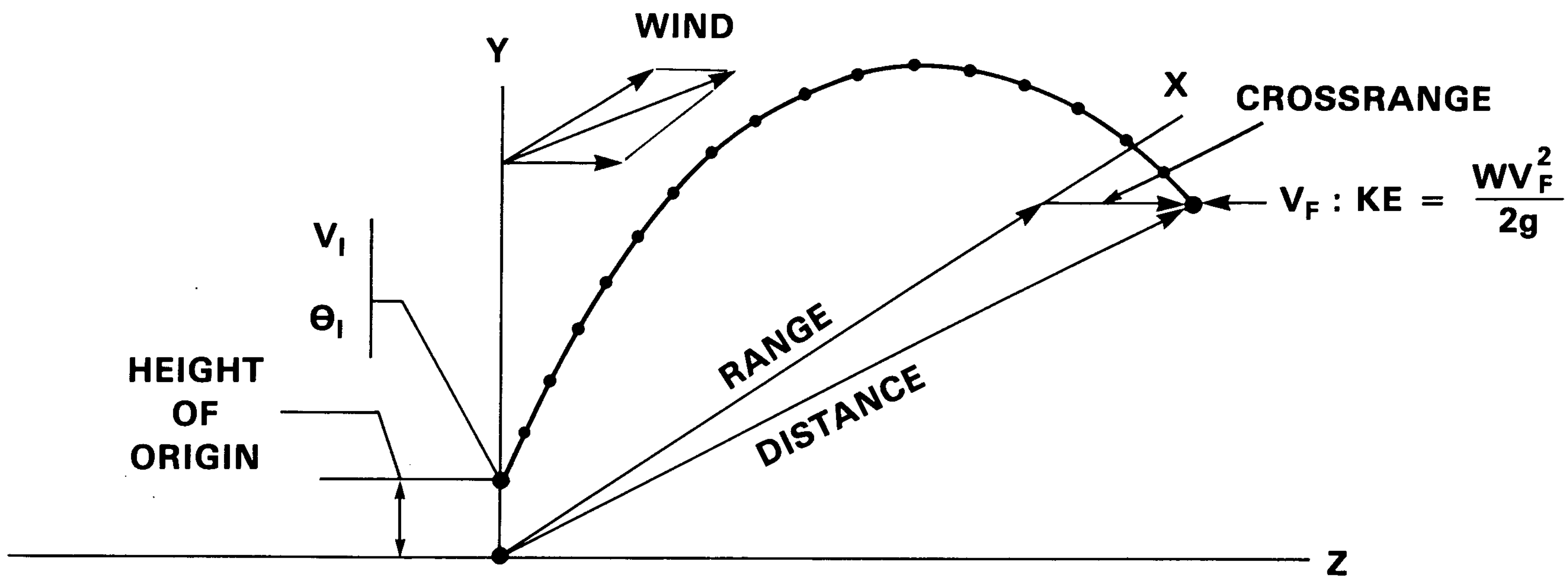


FIG 2 — FRAGMENT TRAJECTORY

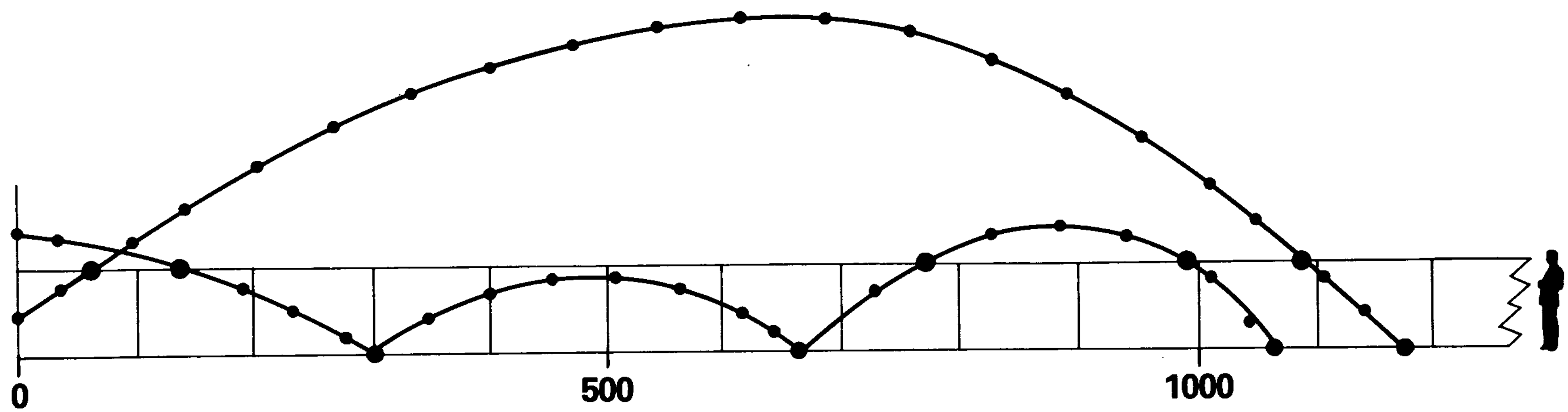
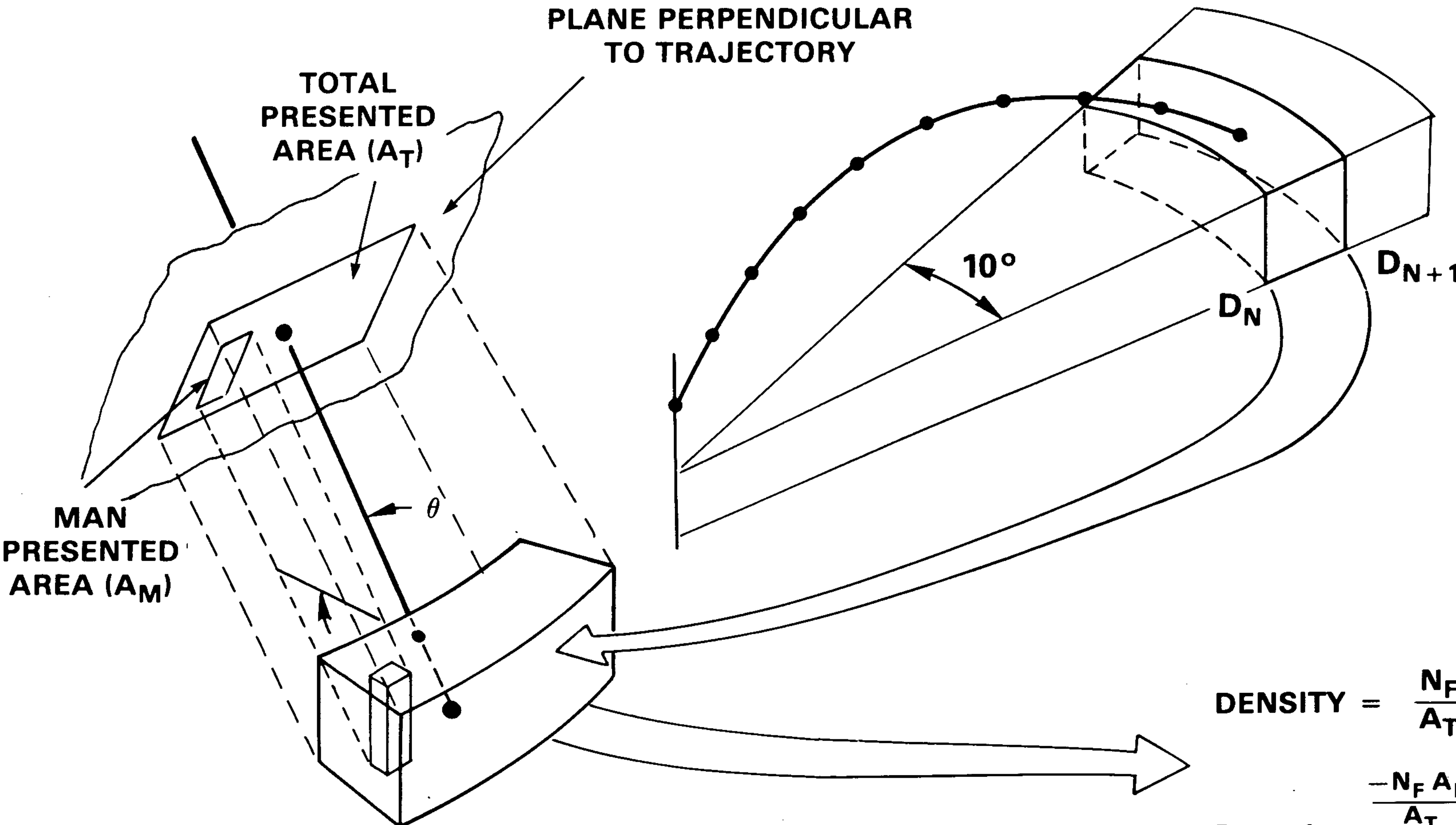


FIG 3 — TYPES OF TRAJECTORIES
1. RICOCHET
2. NON-RICOCHET



$$\text{DENSITY} = \frac{N_F}{A_T}$$

$$P_H = 1 - e^{\frac{-N_F A_M}{A_T}}$$

FIG 4 — HAZARD CALCULATIONS

TABLE 1

TYPICAL FRAGMENTATION INPUT DATA

FRAG NO.	POLAR ZONE	WEIGHT	INITIAL VELOCITY	$\bar{A}/M$	AREA RATIO
1	0-10	623	3246	10.2	6.2
2	0-10	891	3246	9.1	4.7
•	•	•	•	•	•
•	•	•	•	•	•
•	•	•	•	•	•
89	30-40	1021	4831	8.6	5.6
90	30-40	819	4831	12.2	8.2
91	40-50	2162	5814	7.7	6.7
•	•	•	•	•	•
•	•	•	•	•	•
•	•	•	•	•	•
231	110-120	813	4831	9.1	4.9
232	120-130	1421	5772	11.3	13.2
233	120-130	667	5772	7.2	10.6

TABLE 2

NUMBER OF FINAL GROUND IMPACTS 10 deg AZIMUTH SECTOR

DISTANCE	MIN	AVG	MAX
0-200	12	16	21
200-400	5	8	11
400-600	20	25	37
600-800	40	52	67
800-1000	57	71	85
1000-1200	82	97	115
1200-1400	112	127	142
1400-1600	91	104	117
•	•	•	•
•	•	•	•
•	•	•	•
•	•	•	•
4600-4800	0	0	0

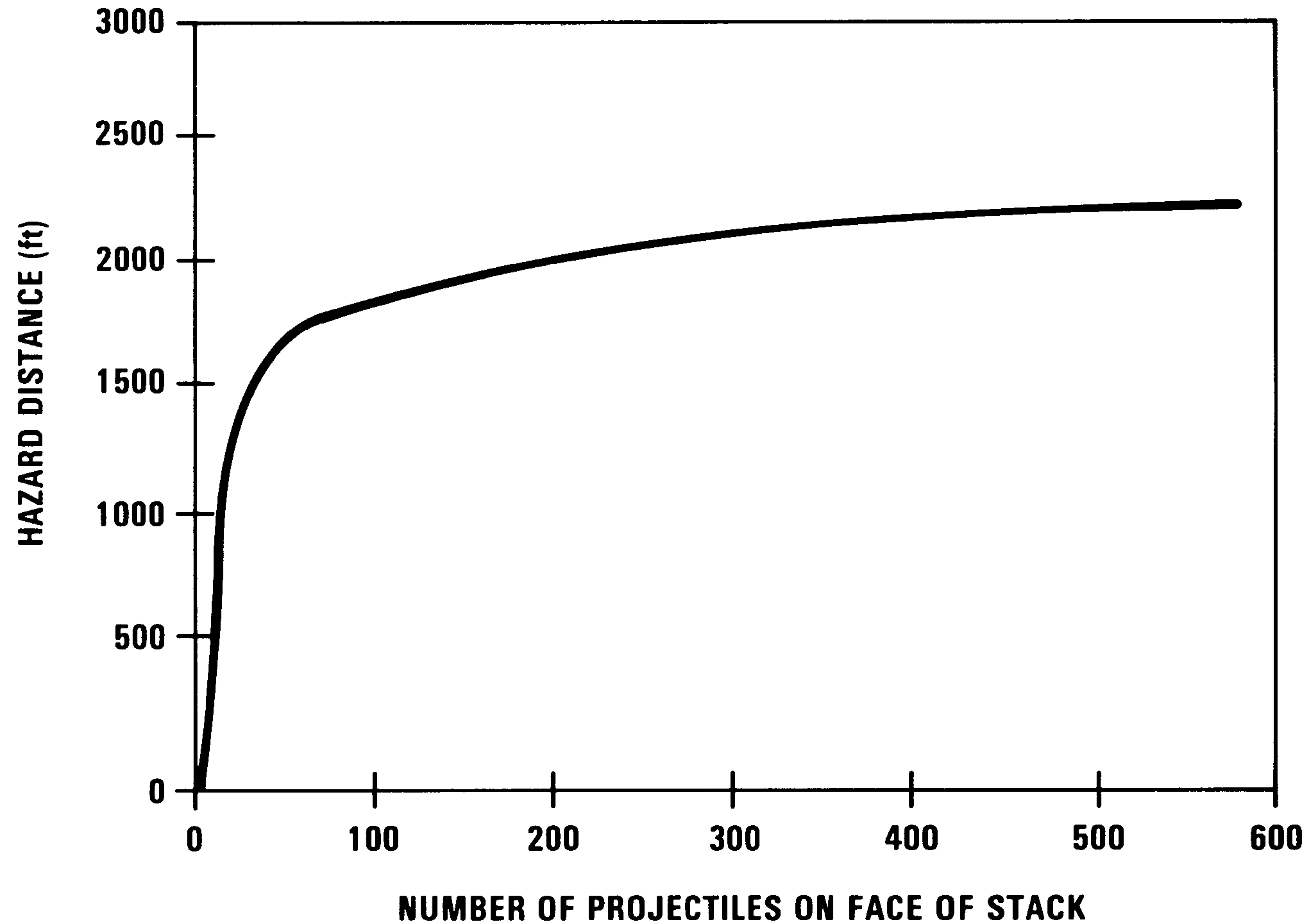
TABLE 3

HAZARD DISTANCE vs. NUMBER OF PROJECTILES
DISTANCE INCREMENT = 200 ft

HAZARD DISTANCE	NUMBER OF PROJECTILES NEEDED TO JUST EXCEED DENSITY CRITERION			
	MIN	90%	AVG	MAX
100	1	1	1	1
300	2	2	3	4
500	4	5	7	11
700	11	12	15	21
900	22	25	31	47
●	●	●	●	●
●	●	●	●	●
●	●	●	●	●
●	●	●	●	●
●	●	●	●	●
4700	999999	999999	999999	999999

FIGURE 5

HAZARD DISTANCE vs. NUMBER OF PROJECTILES PROJECTILE XXX



"BLAST AND FRAGMENT LOADING ON CONTAINMENT STRUCTURES" - A MANUAL OVERVIEW

By

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ABSTRACT

A manual was prepared to aid the government in designing an explosion containment structure (ECS) to be used for the demilitarization of chemical munitions. Other manuals are available for the prediction of blast and fragment loadings; however, these are directed toward bare explosives and conventional munitions. Chemical munitions combine the non-ideal effects of casing, chemical agent around the charge, and non-spherical charge shape. This manual was prepared to direct the user on the procedures to be followed to predict the blast and fragment loading from chemical munitions. Specifically, the loadings are those to be used in the design of an ECS in a demilitarization facility. During the preparation of this manual, tests were performed at NSWC, Dahlgren, Virginia, to supplement the very limited previous data base for both blast and fragments and to confirm the applicability of the prediction procedures presented here. The munitions tested are those planned for demilitarization at Johnston Island (JI); however, the manual is written to be general for all chemical munitions and demilitarization facilities.

ACKNOWLEDGEMENTS

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INTRODUCTION

A variety of manuals are available for determination of blast and fragment loads applied to structures when a high explosive material detonates inside an enclosure. The prediction methodologies presented in these manuals are applicable to a wide variety of explosive sources. In addition to the wealth of information collected on high explosive materials alone, numerous investigations into the blast and fragmentation properties of munitions which contain high explosives have been conducted, quantified, and included in the technical manuals. In the past, munitions which contained a large part of their total weights as high explosive material were or primary interest to hazards researchers and weapons designers. These munitions often are designed to produce a dangerous blast field and project high velocity fragments. Chemical weapons have different characteristics. The explosives inside chemical weapons serve only to rupture the casing and disperse the chemical agent. The generation of a dangerous blast field or projection of hazardous fragmentation by chemical weapons has never been a design goal. Thus, extensive testing to characterize these parameters has, in the past, never been pursued and no significant data base has been developed from which to quantify the blast and fragmentation of chemical weapons. Consequently, it was unknown whether existing manuals which present prediction methodologies based on data for bare explosives and conventional munitions could be used with confidence to quantify the hazards associated with the detonation of chemical munitions. This uncertainty conflicts with the confidence one desires in explosion containment structure (ECS) design and was the reason for developing a manual aimed specifically at chemical munitions.

During the preparation of this manual, tests were performed at the Naval Surface Weapons Center (NSWC) to supplement the very limited previous data base for both blast and fragment data and to confirm the applicability of the prediction procedures presented herein. Beyond this, the prediction methodologies are applied to a variety of ECS configurations, and conceptual designs of several containment structures are compared.

The manual is organized into two voluems. Volume I includes the chapters presented below. In the chapters, numerous calculations are referenced to support conclusions. These calculations, along with concept design calculations are included in Volume II. Reference is made throughout the manual

to the proper location in the calculation appendices for user cross-reference.

Chapter	Topic
1	Introduction
2	Fragmentation
3	Blast and Fragment Load Estimation Procedures
4	ECS Loading
5	Evaluation of ECS Configurations
6	Candidate ECS Conceptual Designs

This manual develops techniques which are general in nature and can be applied to a variety of chemical demil facilities. However, the majority of the analysis and related testing is very applicable to the Johnson Atoll Chemical Agent Disposal System (JACADS) the design of which is currently under development. Blast and fragment loads used in the design of this system are predicted using the subject manual. This work was completed under the technical direction of the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) and the U.S. Army Corps of Engineers, Huntsville Division (USAEDH) under contract number DACA87-81-C-0099. Copies of this manual should be requested through these organizations.

Chapter 2 - Fragmentation

This chapter contains the following subjects:

1) Empirical prediction models for conventional (nonchemical) munitions.
2) A review of current published literature and data pertaining to chemical munition fragmentation studies.
3) Application of prediction models to specific chemical munitions.
4) Comparison of predictions to arena test data.
5) Estimates of the worst case fragment threat, based on analysis of NSWC arena test data, for the M426 projectile, M55 rocket, and M23 mine.

A considerable amount of work has been done to develop analytical models for predicting the fragmentation characteristics of conventional munitions loaded with high explosives (HE). However, all typical prediction models assume that the HE is in intimate contact with the munitions wall or case. To our knowledge, very little work had been done to develop fragmentation

prediction models for munitions where HE is separated from the munition wall by a chemical agent, or other fluid. The purpose of this chapter was to fill this gap and to identify "worst case" fragments of specific chemical weapons.

The following parameters must be known of a fragment at impact to determine the relative damage potential to a given target: velocity mass, shape, orientation, and material properties. Standard prediction methodologies exist for the calculation of fragment velocity and mass distributions for conventional cased munitions. These methodologies were adapted to chemical munitions by including the mass of the chemical agent and burster wall in the computational procedures. Use of the modified procedures was compared to test data collected during preparation of this manual and some data that existed previously.

The reader is cautioned several times in the manual that one should choose test data, if available and of good quality, to make his determination of the worst case fragment emanating from the detonation of a given chemical munition, over the results obtained from the analytical procedures. This suggestion is based on a literature review of arena test data on the M122, M426, M55, and M23 chemical munitions, and on arena tests conducted by NSWC, Reference 1. The data base was very limited, except for the M121 projectile. The data base for the M426 projectile and M55 rocket were very limited, and no test data were available for the M23 mine.

Due to the limited data base, additional arena tests were conducted at NSWC. The test program was divided into two phases. The purpose of Phase I was to determine:

a) Fragmentation patterns
b) Orientation of munitions and velocity screens for Phase II tests.
c) Location of fragment recovery bundles for Phase II tests.

The test setup for Phase I included 360° of steel witness plates and camera coverage. The Phase II tests were the actual arena tests. Three rounds each of the M426 projectile, the M55 rocket, and the M23 mine were detonated to generate fragment dispersion into the wallboard recovery media. Fragments were recovered and weighed after the third shot for each type munition. The munition orientation and wallboard locations are illustrated in Figures 1 through 3. Blast measurements at the locations identified in Figures 2 and 3 were made to provide blast data. Each wallboard was divided into five

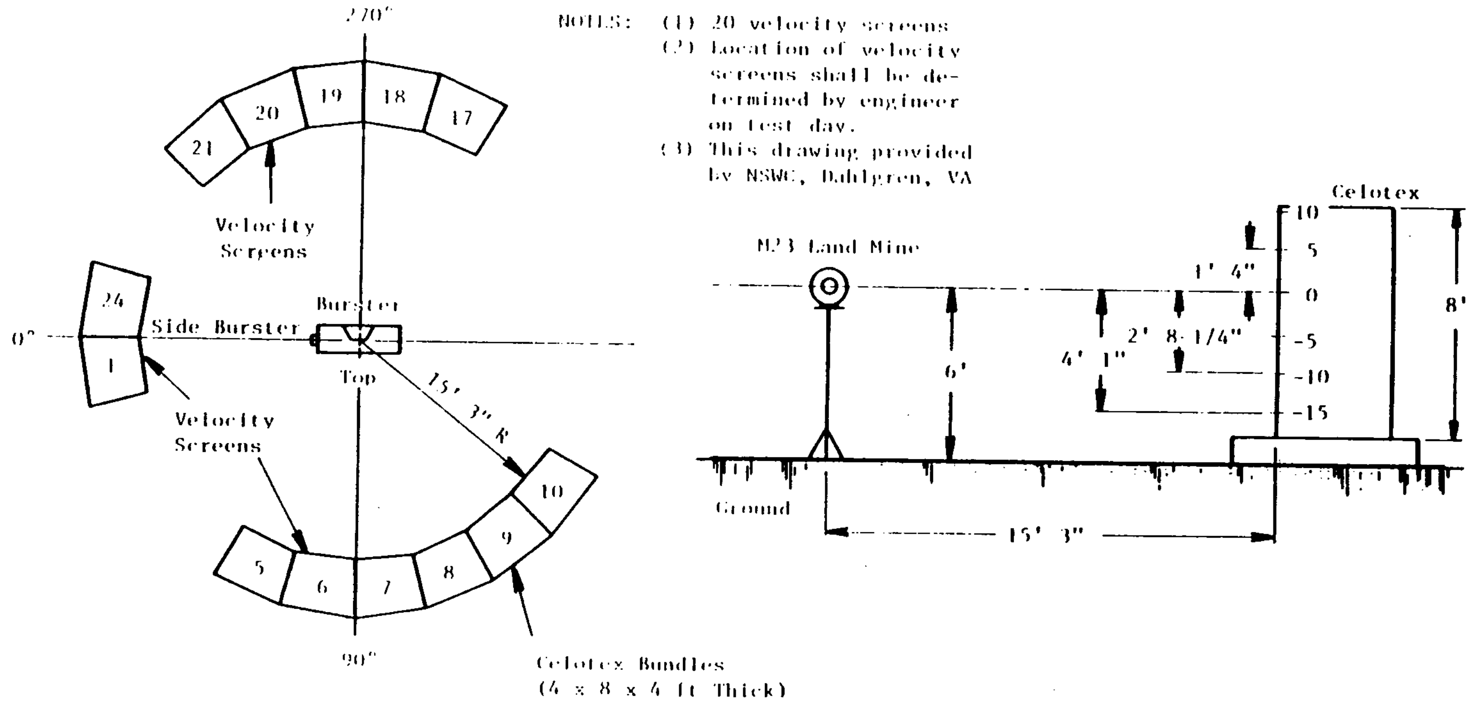
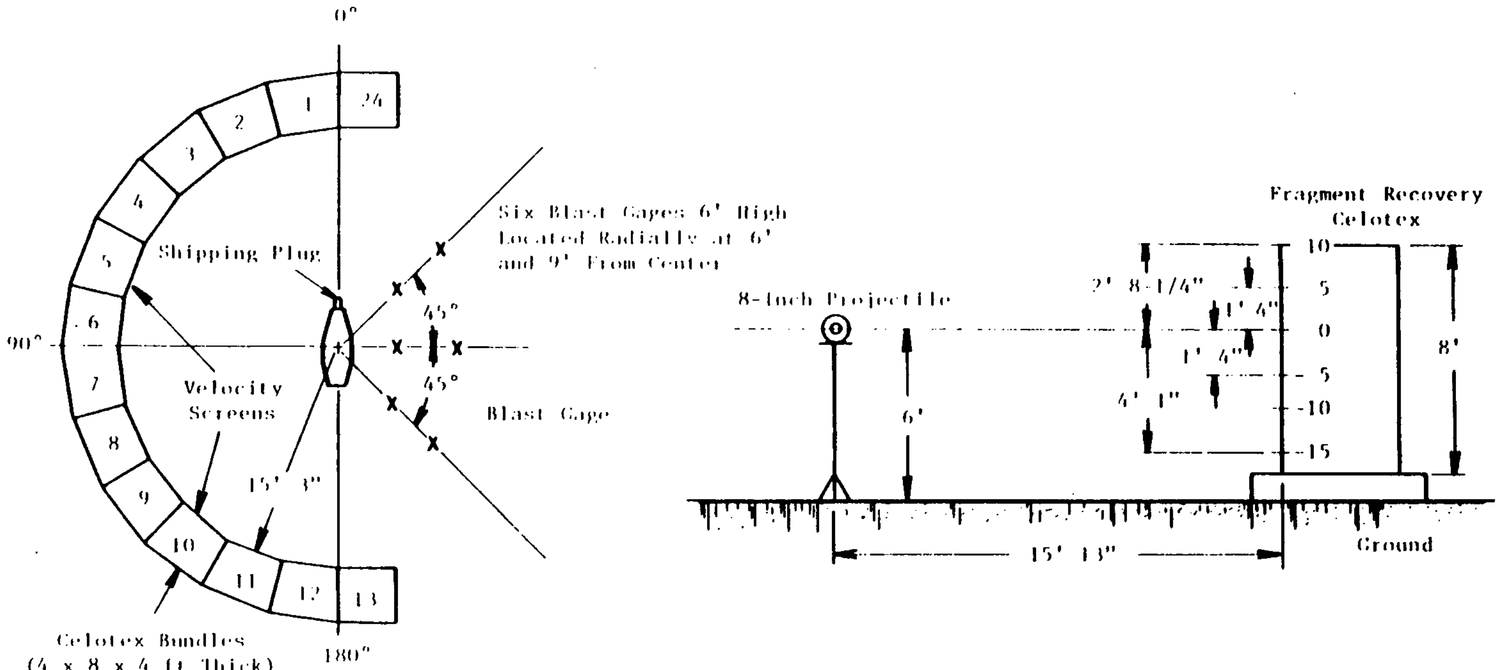
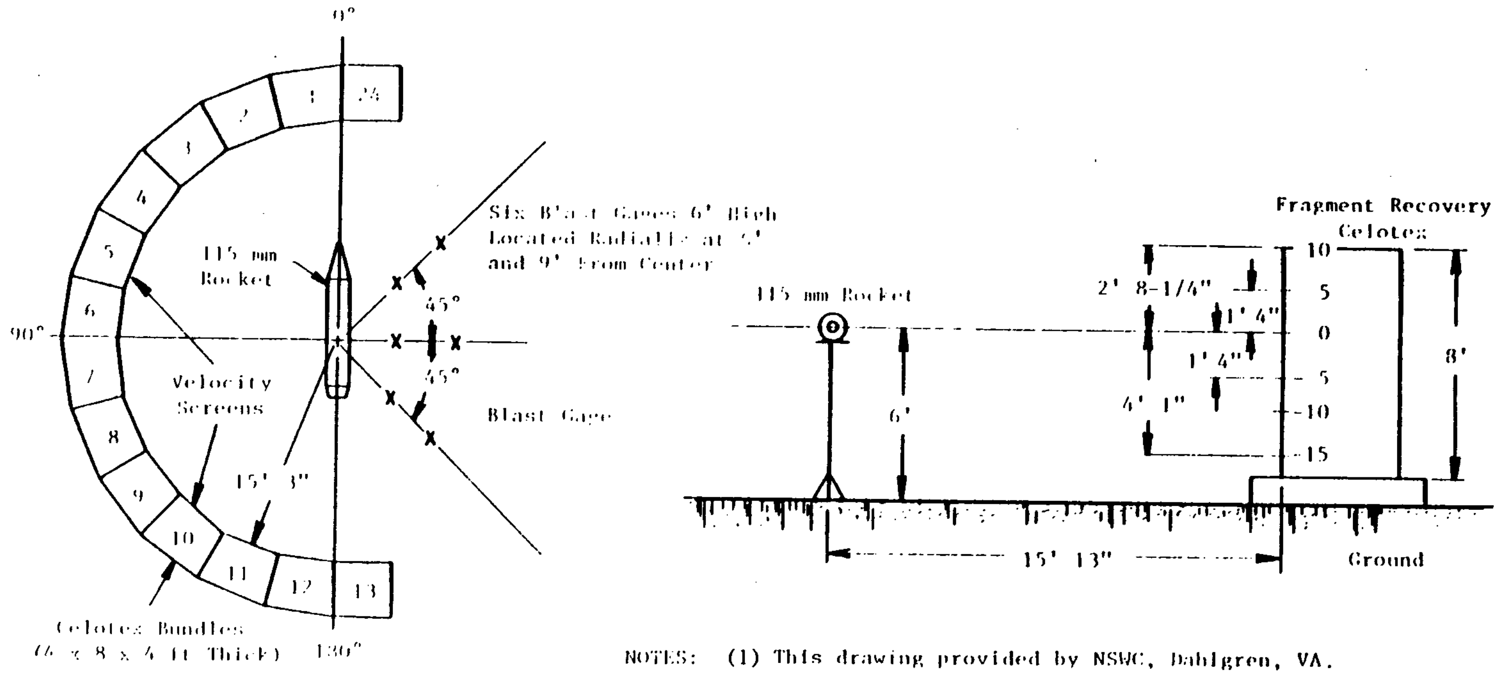


Figure 1. Chemical Munitions Program -- M23 Land Mine Fragment Recovery



NOTE: This drawing provided by NSWC, Dahlgren, VA

Figure 2. Chemical Numitions Program -- 8-Inch Chemical Projectile Fragment Recovery



NOTES: (1) This drawing provided by NSWC, Dahlgren, VA.
(2) The rocket is inside the fiberglass shipping container during testing.

Figure 3. Chemical Munitions Program -- 115 mm Chemical Rocket Fragment Recovery

zones, as illustrated in Figure 4. Velocity screens were placed at various zone locations on the wallboard recovery media in an attempt to relate recovered fragments to the measured velocities. Of course, more than one fragment penetrated each screen, but this still resulted in a method of identifying groups of fragments to a velocity.

The modified analytical procedure for prediction of fragment mass and velocity distributions agreed reasonably well with test data for chemical munitions of regular, simple geometry such as the M122 and M426 projectile. These computations did not correlate as well, however, with the M55 rocket or M23 mine arena test data. The M55 rocket and M23 mine both had more complex geometries, and the rocket was cased of aluminum instead of steel, and the mine had assymetrical charge positions. The fragment breakup pattern of chemical munitions was similar to that obtained from bursting pressure vessels, fragments having great variability in shape.

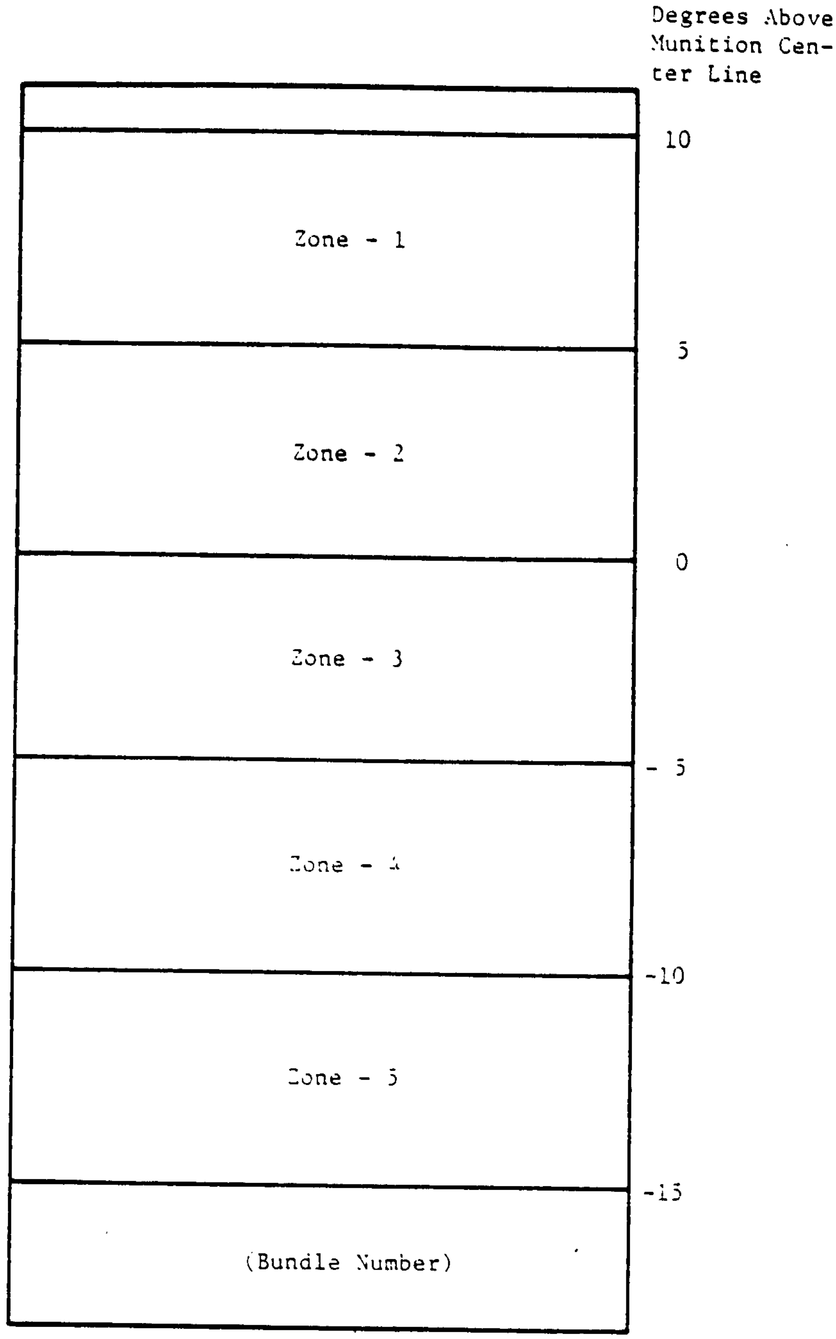
A safety factor is commonly used to determine blast loads for design of blast-resistant structures. A typical safety factor is to increase the effective charge weight by 25 percent. It is recommended that a safety factor not be used in fragmentation calculations, regardless of whether the worst case fragment is analytically or experimentally determined because the criteria for selection of worst case fragment and penetration calculations are conservative; hence, a built in safety factor is obtained.

Chapter 3 - Blast and Fragment Load Estimation Procedures

A review of existing manuals and documents concerned with air blast loading and fragmentation loading (penetration capability) is provided to direct the user to additional background information. The first responsibility of the chapter is to give blast prediction techniques. A general discussion of air blast phenomenology and scaling is presented along with prediction curves for air blast loading. As examples Figures 5 and 6 can be used to determine blast pressure and specific impulse at scaled distances about a plate surface.

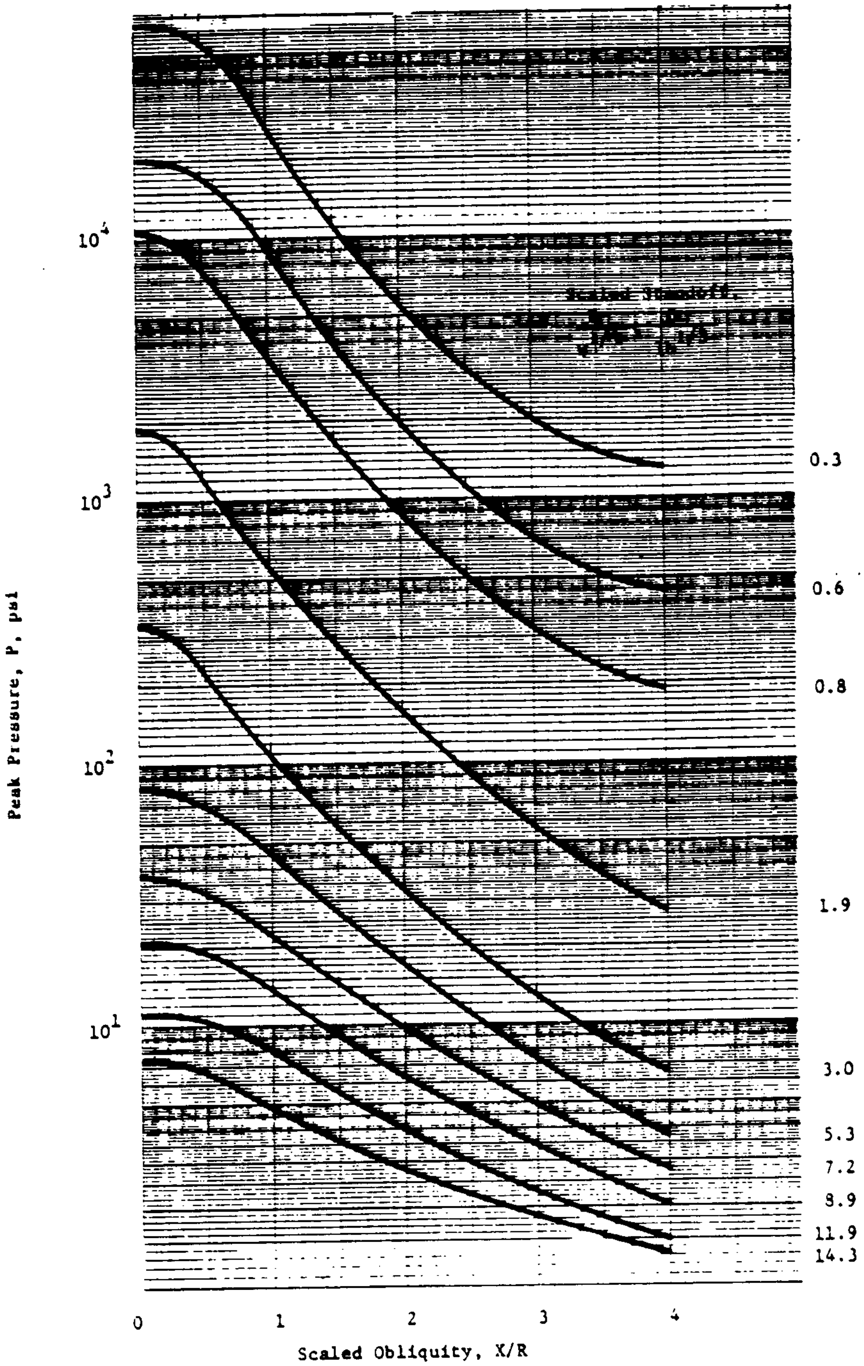
In Chapter 3 the effects of non-ideal blast effects of chemical weapons is analyzed. These include

- Casing about the charge
- Agent about the charge



NOTE: This drawing provided by NSWC, Dahlgren, VA

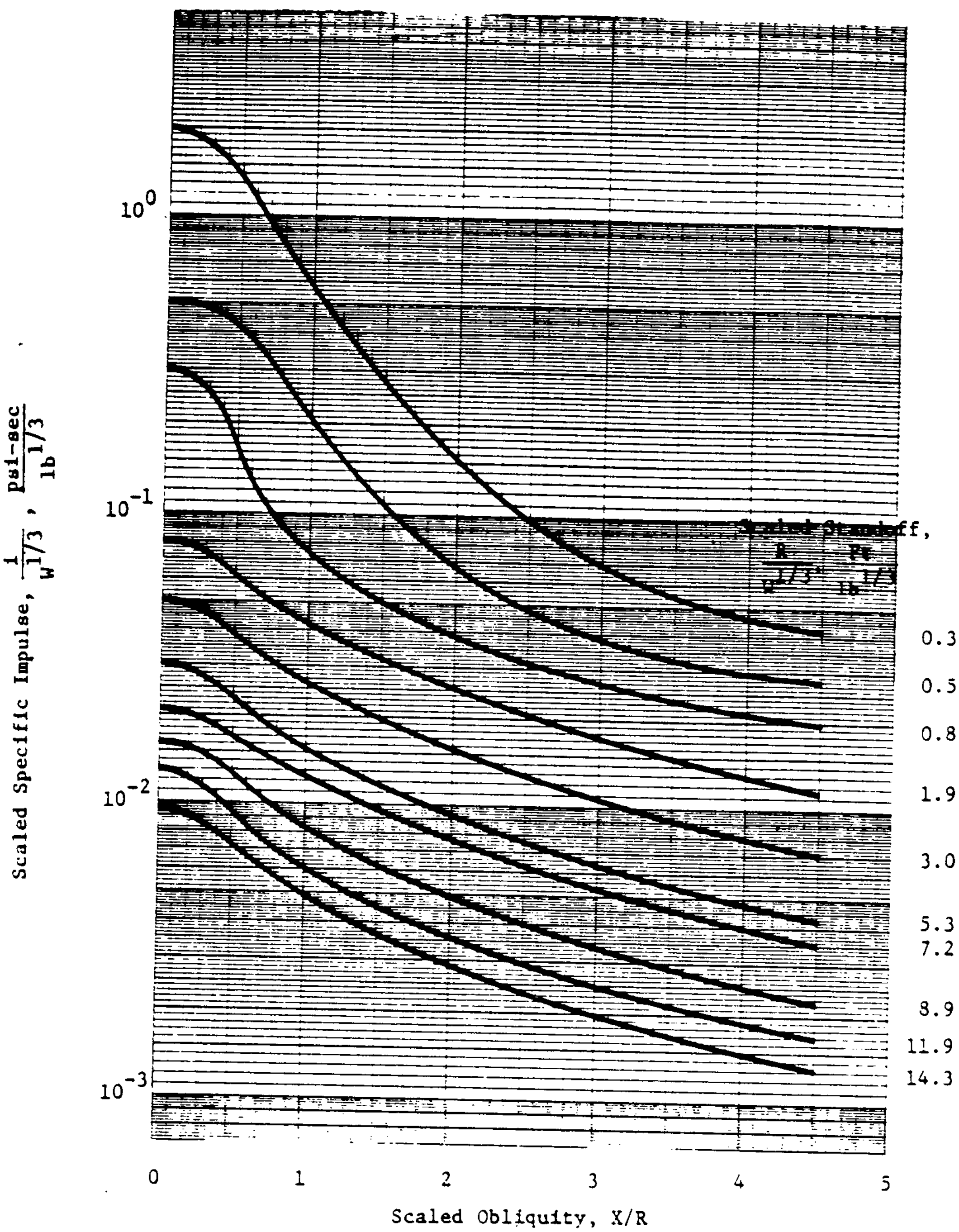
Figure 4. Zone Layout for Each Recovery Bundle



where R = perpendicular standoff, ft
X = distance on surface to point of interest, ft
W = charge weight (TNT equivalent), lb

NOTE: Full-Sized Figures are Attached at End of Report

Figure 5. Peak Pressure for Oblique Shocks for $0 \leq X/R \leq 4$



where R = scaled standoff, ft
X = distance on surface to point of interest, ft
W = charge weight (TNT equivalent), lb

NOTE: Full-Sized Figures are Attached at End of Report

Figure 6. **Scaled Specific Impulse for Oblique Shocks for $0 \leq X/R \leq 4$**

- Shape (cylindrical, large L/D)
- Type of explosive

The data collected during the NSWC testing was analyzed and compared with predictions from air blast curves to determine the best procedure to use.

This chapter includes detailed discussion about the effects of confinement on blast loading. This is an important feature as the chemical weapons will be demiled inside a containment chamber. Finally, a detailed working procedure is given to direct the user in applications.

The second responsibility of Chapter 3 is to provide the designer with the means to predict fragment penetration, perforation, and spall for the worst case fragments identified in Chapter 2. Penetration equations are for fragments into both steel and concrete targets. The limits of applicability of each technique are tabulated for velocity, shape, and material.

<u>Chapter 4 - ECS Loading</u>

In Chapter 4 the blast and fragmentation loading prediction procedures detailed in Chapter 3 are applied to various structural containment shapes. These include the following:

- Rectangular chamber
- Horizontal cylinder chamber
- Vertical cylinder chamber
- Spherical chamber

Blast loads on the following structural elements were predicted to provide the designer example calculations to follow in applications.

- Roof slabs
- Walls slabs
- Ring sections
- End caps
- Spherical elements
- Doors

The fragment penetration equations in Chapter 3 were applied to both steel and concrete materials. The results of both blast and fragmentation loads are summarized along with detailed calculations in Volume II of the manual.

Chapter 5 - Evaluation of Explosion Containment Structure Configurations

There are many possible configurations and materials of construction for the explosive containment structure (ECS) or chambers. These include.

a) Horizontal steel cylinder or arch
b) Horizontal reinforced concrete cylinder or arch with or without steel liner
c) Vertical steel cylinder
d) Vertical reinforced concrete cylinder with or without steel liner
e) Reinforced concrete rectangular chamber with or without steel liner
f) Spherical steel chamber
g) Double-walled steel structure with concrete filler - Rectangular configuration

These configurations were examined and compared based upon the following:

- Structural Integrity
- Size Requirements
- Constructability

The advantages and disadvantages of each configuration were listed and three ECS concepts were chosen for a more detailed evaluation inch six. An overview of some of the more important aspects are listed below.

Structural Integrity - A discussion of example existing explosion containment structures, both steel and concrete, is presented in the manual. Many of these structures have been explosion tested or are routinely subjected to internal explosions at research laboratories, References 2 through 12. The conclusion was that structural integrity with containment could be achieved, and analytical methods are available to accomplish this, for any of the configurations.

Size requirements - The ECS configurations must be large enough to surround the work envelope necessary for equipment and work space. The work envelope is sized by the equipment and operational room around these equipment. For purposes of the manual a rectangular work envelope of 25W x 27L x 16H feet was chosen. This is a representative example of an ECR work envelope; actual

sizes for a specific demil system may vary. Rectangular configurations fit this shape exactly; sphere, cylinder, and arch shapes do not. As an example, a sphere would have a 40 foot diameter to fit around the work envelope. A discussion on how the different configurations shapes for containment chambers would fit into the entire demil facility was made. Rectangular shapes adapt to a demil facility made of box-shaped rooms with flat floors. This allows door entry without drops, steps, or false floors in the containment chamber. Horizontal cylinders and arch shapes are less desirable from this standpoint, but much more desirable than vertical cylinders and spherical shapes.

Constructability - Fragment perforation has led to very thick wall steel structures, much thicker than typical pressure vessels. This fact and the size of the steel configurations would require field erection rather than being built elsewhere and shipped. The steel thickness are such that considerable labor is involved including full penetration welds. Reinforced concrete thicknesses pose no special construction problems. Flat surface forming is preferred over curved; however, it is possible to construct the concrete cylindrical and arch configurations. The location of doors on the various configurations identified can lead to problems such as designed for curved surfaces and the presence of stress concentrations about door openings in the containment shell. Door penetrations on flat surfaces are preferred as is found with the rectangular and horizontal cylinder shapes (on end walls).

A comparison of the various configurations is provided in Table 1. It was determined that none of the curved structures (arch, cylinders, sphere) were suitable for containment of an explosion involving the chemical weapon understudy. The following concepts were chosen for further study.

- Reinforced concrete rectangular chamber
- Steel rectangular chamber
- Double-walled steel framework rectangular chamber with concrete fill.

Chapter 6 - Candidate ECS Conceptual Designs

The three designs chosen in Chapter 5 were analyzed in detail in this chapter. Construction considerations are discussed along with design methods and allowable design deflections. A summary of the three designs is provided with a complete accounting of all design analysis provided in Volume II. The

Table 1. ECS Concept Evaluation

Configuration	Material	Dimensions (ft)			Volume (ft^3)	Surface Area (ft^2)	Door On Curved Surface	End Cap Size (ft)	Floor Required	Shape Conform To Rectangular Shaped Facility	Preferred Based On Decontamination
		Length	Width	Height							
Horizontal Cylinder	Steel	27.0	29.7	29.7	18,700	3,920	No	29.7	Yes	No	Yes
Horizontal Cylinder	Concrete	27.0	29.7	29.7	18,700	3,920	No	29.7	Yes	No	No
Horizontal Arch	Steel	27.0	20.3	20.3	17,500	3,017	No	20.3	No	No	Yes
Horizontal Arch	Concrete	27.0	20.3	20.3	17,500	3,017	No	20.3	No	No	No
Vertical Cylinder	Steel	36.8	36.8	16.0	17,000	3,980	Yes	36.8	No	No	Yes
Vertical Cylinder	Concrete	36.8	36.8	16.0	17,000	3,980	Yes	36.8	No	No	No
Rectangular Chamber	Steel	27.0	25.0	16.0	10,800	3,014	No	16.0	No	Yes	Yes
Rectangular Chamber	Concrete	27.0	25.0	16.0	10,800	3,014	No	16.0	No	Yes	No
Rectangular Chamber	Steel Framework	27.0	25.0	16.0	10,800	3,014	No	16.0	No	Yes	No
Spherical Chamber	Steel	40.1	40.1	40.1	36,000	5,280	Yes	N/A	Yes	No	Yes
Spherical Chamber	Concrete	40.1	40.1	40.1	36,000	5,280	Yes	N/A	Yes	No	No

designs were taken far enough in detail to provide material quantity survey and cost comparisons.

Conclusions - A manual was developed that provides the designer the capability to predict blast and fragmentation loadings from chemical weapons. Development of possible containment chambers concepts was provided.

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SPARROW (7M) HAZARDS TEST PROGRAM

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ABSTRACT

This test program was conducted to 1) determine the sympathetic detonation propagation characteristics for the warhead and the rocket motor components of the SPARROW (7M) weapon and 2) establish fragment and airblast hazard environments for the warhead. Test results are compared with predictions. Sympathetic detonation propagation results for United States Air Force handling configurations are discussed. Specifically, nose-to-tail missile stacking orientations, which align warhead and rocket motor sections, are shown to be a means for limiting propagation of sympathetic detonation. Fragment and airblast hazard ranges for the warhead are presented.

BACKGROUND

The Naval Surface Weapons Center (NSWC) previously conducted a Quantity-Distance (Q-D) study for handling operations involving the SPARROW (AIM/RIM-7M) with the WAU-17/B (EX 114 MOD 1) warhead.[1] This analytical study determined the likelihood of sympathetic detonation and hence the Maximum Credible Event (MCE) for the SPARROW weapon system for Navy pier and ship configurations. It also determined the acceptable hazard ranges for blast and fragment effects for the various scenario MCE's. The results of that study indicated that, when handling 11 or fewer missiles, the SPARROW missile with the WAU-17/B warhead did not constitute a hazard for the Navy in pierside and shipboard transportation/handling configurations beyond a range of 152 m (500 ft).

Subsequent Air Force evaluation of the general airblast/fragment hazards for the various MCE's indicated that the SPARROW (AIM-7M) with the WAU-17/B warhead could be a significant problem for handling and storage at Air Force bases. Hence, the Naval Surface Weapons Center and the Naval Weapons Center (NWC) were tasked to determine, by testing, the hazards associated with the SPARROW (7M) for various Air Force shipping and handling scenarios.*

*This task was performed under Project Order Document Number N0001984P04827P for the Air-to-Air Missile Systems Project Office for SPARROW (PMA-259B, LTCOL R. Hudkins, USAF), Naval Air Systems Command.

OBJECTIVES

The specific objectives of the program were:

1. Determine sympathetic detonation propagation characteristics for the WAU-17/B warhead and the MK 58 rocket motor components of the SPARROW (7M) weapon system for the USAF CNU-305 shipping container, munitions transport trailer, and proposed high density rack configurations.

2. Establish the fragment and airbalst hazard ranges for the WAU-17/B warhead. Compare these test results with theoretically predicted values.

EXPERIMENTAL PROGRAM

The test program was conducted at two test sites. The sympathetic detonation propagation tests were conducted at NSWC, Dahlgren, VA, Laboratory, and the warhead fragment recovery tests were conducted at NWC, China Lake, CA.

Propagation Test Setup

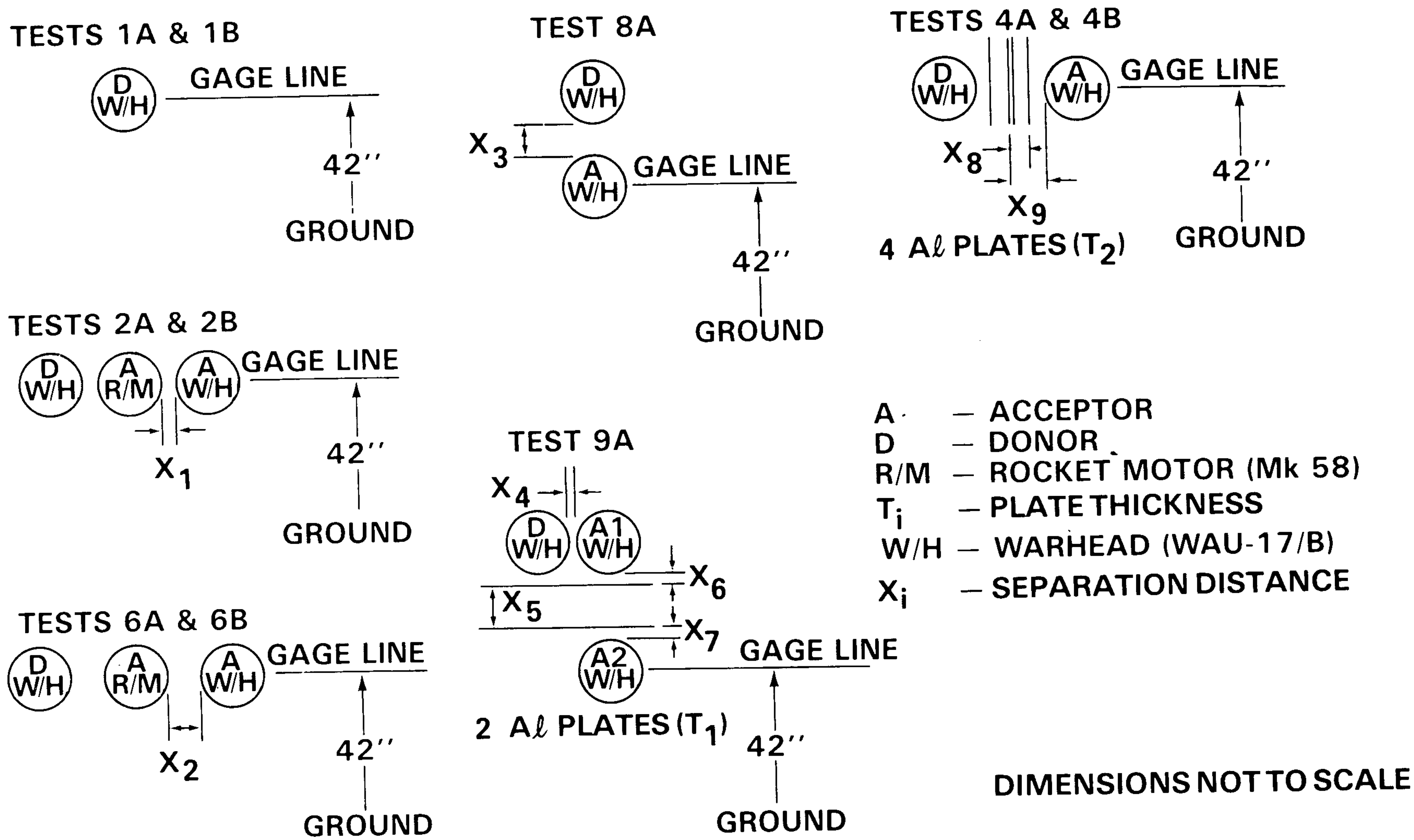
The six warhead/rocket motor configurations used for the ten sympathetic detonation tests are shown in Figure 1. The order of the tests is: 1A, 1B, 2A, 2B, 6A, 6B, 4A, 4B, 8A, and 9A. The order of the tests was dependent on the outcome of the acceptor responses (detonation/non-detonation). The test logic was provided by Eglin AFB (AD/SES) and Norton AFB (AFISC/SEV) to address specific Air Force Handling/storage configurations. Only the test sequence as conducted here will be discussed.

Predictions. Estimates of close-in shock/fragment environments were prepared in order to predict the acceptor rocket motor/warhead response for the propagation tests. The Naval Explosives Safety Improvement Program (NESIP) technology base[2,3] was used to perform these close-in explosion environment estimates and acceptor responses. Methods (and results) for estimating close-in SPARROW WAU-17/B airblast/fragment environments are given in reference 1. Estimates of the card gap values for the NOL Large Scale Gap Test[4] were used as threshold values for evaluating detonation response to shock (direct shock and fragment impact) for the acceptor propellant and explosive.

Field Setup. Churchill Section, Explosion Experimental Area, Pumpkin Neck, Dahlgren Laboratory[5] was prepared as the test site. Surveys were made to establish locations for ground zero, airblast gages, and cameras. Base (ground) plates were positioned at ground zero. All warheads and rocket motors were aligned in a horizontal orientation relative to ground zero. A donor Warhead was detonated for all events using modified SPARROW S & A devices.

Witness Plates. Thick (1-2 inches) steel plates were aligned with the acceptor components for determining detonation/non-detonation responses for the acceptors. A holing of the witness plate over the dimension of the acceptor indicates a detonation response.

FIGURE 1. TEST HARDWARE CONFIGURATION



Airblast. Airblast data were recorded using twelve gages (six gage positions) for the first eight tests and six gages at the three far gage positions for the last two tests. PCB Piezotronics Model ST-7 and Celesco Model LC-33 transducers were used.

Photographic Coverage. The explosion events were recorded using 44,000 pictures/second HYCAM, 6,000 frames/second FASTAX and 400/24 frames/second LOCAM cameras. The HYCAM data films were used to determine detonation/non-detonation response for the acceptors. An observation of the white "first light" indicates donor/acceptor detonation.

Weather. Barometric pressure, temperature, and wind speed/direction at test site/time were recorded.

As indicated above, several indicators were employed for establishing the detonation/non-detonation response of the acceptor rocket motors/warheads. Several of these indicators were useful immediately following the test: (1) post-test observation of ground zero vicinity - evidence of acceptor debris, (2) damage to witness plates, and (3) quick look at airblast data printouts. The acceptor responses were further confirmed by analysis of the HYCAM data films available within one-to-two days following the test and by a detailed interpretation of the airblast data which followed within about a month of test completion.

A brief description of each test configuration follows (refer to Fig. 1).

Tests 1A and 1B. These tests were calibration shots for the airblast instrumentation. For each of these tests a single warhead was detonated.

Tests 2A and 2B. These tests addressed the concept of limiting sympathetic detonation propagation by orienting the missiles in a nose-to-tail configuration, which aligns warhead and rocket motor sections side by side. An acceptor MK 58 rocket motor was positioned between donor and acceptor warheads for this test. The spacing between test items is an average value for spacing encountered in the USAF CNU-305 shipping container.

Tests 6A and 6B. These tests had a nose-to-tail configuration similar to tests 2A and 2B. However, in these tests the spacing between the acceptor rocket motor and the donor and acceptor warheads corresponds to spacings encountered with the USAF munitions transport trailer and the proposed high-density rack.

Tests 4A and 4B. These tests addressed the propagation of sympathetic detonation between warheads aligned in separate USAF CNU-305 shipping containers positioned side by side. The spacing between the donor and acceptor warhead is typical of side-by-side spacings for these containers. The four aluminum plates simulate (materials, spacings and minimum thicknesses) the two double side-wall thicknesses for the shipping containers.

Test 8A. This test addressed the propagation of sympathetic detonation between warheads aligned side by side at separation distances representative of missile spacings on the USAF munitions transport trailer and the proposed high-density rack.

Test 9A. This test addressed the popagation of sympathetic detonation between warheads aligned in separate USAF CNU-305 shipping containers stacked vertically. The donor warhead position was selected as shown in Fig. 1 in order to direct any interaction jet formed between the donor warhead and the adjacent warhead (A1) towards the second acceptor warhead (A2). The horizontal spacing between the donor warhead and A1 is the close-missile spacing in the USAF CNU-305 shipping container. The vertical separation corresponds to the missile spacing for vertical stacking of the shipping containers. The two aluminum plates simulate (materials, spacings and thicknesses) the single wall construction for the top and bottom walls of the shipping containers.

Fragment Recovery Test Setup

The test configuration for the warhead fragment recovery tests consisted of a 30° sector prepared for fragment collection over the range increment 120-1200 m (400-4000 ft). Each of the warheads (tested separately) was positioned (horizontally) at a height of 610 mm (24 in) above a steel ground plate.

Predictions. Analytical fragment hazard results discussed in reference 1 were used as predictions for the fragment recovery test.

Field Setup. The fragment recovery tests were conducted at Barricade 3, Area R, (Warhead Test Branch, Naval Weapons Center, China Lake.) The test site was prepared (cleared/rolled) and surveyed. A large base (ground) plate was positioned at ground zero. The warhead was detonated for all events using modified SPARROW S & A devices.

Airblast. Airblast data were recorded using six gages (three gage positions) for each test. PCB Model 102 piezoelectric transducers were used.

Photographic Coverage. The explosion events were documented using half-frame PHOTEC and full-frame FASTAX cameras.

Weather. Barometric pressure, temperature, and wind speed/direction at test site/time were recorded.

Fragment Recovery Operation. The recovery area was swept once for fragments following the three single warhead detonations. Fragments were identified (marked) and surveyed in place.

SYMPATHETIC DETONATION

A brief description of each test result follows (refer to Fig. 1).

Tests 1A and 1B. Base (ground) plate indicated proper fragment formation/ejection. This result is repeated for all subsequent tests. Data films indicated the donor warheads detonated. Airblast data correlated well between shots ($r^2 = 0.95$, r^2 is the correlation coefficient).

Tests 2A and 2B. Burning propellant and explosive as well as acceptor warhead and rocket motor debris were scattered around ground zero. High speed film data and witness plates indicated that only the donor warhead detonated and that the acceptors violently reacted. Airblast data indicated that the acceptor reactions contributed significantly to the energy release. Airblast data correlated well between shots ($r^2 = 0.95$).

Tests 6A and 6B. Burning propellant and rocket motor case debris were scattered around ground zero. The acceptor warheads were translated intact. The acceptor warhead impact locations were within three meters of each other for the two tests. High speed film data and witness plates indicated that only the donor warhead detonated and the acceptor rocket motor violently reacted. Airblast data correlated well between shots ($r^2 = 0.97$).

Tests 4A and 4B. Acceptor warhead case debris were scattered around ground zero. High speed film data and witness plates indicated that the donor warhead detonated and that the acceptor warhead violently reacted. Airblast data indicated that the acceptor warhead energy release was insignificant. Airblast data correlated well between shots ($r^2 = 0.95$).

Test 8A. No evidence of acceptor warhead case debris was located at the test site. High speed film data and the witness plate indicated that both the donor and the acceptor warheads detonated. Airblast data indicated that the acceptor warhead contributed significantly to the energy release.

Test 9A. No evidence of debris from either of the two acceptor warheads was located at the test site. The high speed data film clearly indicated that the donor warhead and the acceptor warhead A1 detonated. Less clear indication for detonation was noted in the film for acceptor A2, although the "first light" was observed. The witness plate indicated that the donor and both acceptors detonated. The airblast data indicated an energy release equivalent to three warhead detonations.

Propagation. Table 1 lists the configurations tested and gives a comparison between the predicted and experimental results for sympathetic detonation. The only surprise produced by the test results is for test configuration 4. The prediction for fragment impact-induced shock (42 kbars) greatly exceeds the estimated threshold for detonation (17 kbars) for the warhead explosive. In fact, the fragment impact-induced shock pressures for configuration 4 and configuration 9 (which did exhibit sympathetic detonation propagation for acceptor A2) are comparable. There are obviously other effects, such as fragment deflections and multiple plate interactions, that are coming into play here that are not accounted for in the simple prediction model employed.

AIRBLAST HAZARD

The airblast data were collected at two different test sites: NWC, China Lake, CA and NSWC, Dahlgren, VA. The NWC data consisted of three bare warhead shots, whereas the NSWC data contained two base warhead shots. Both sets of data correlated quite well ($r^2 = 0.95$, r^2 is the correlation coefficient).

Table I. Comparison Between Predictions and Experimental Results for SPARROW (7M) Sympathetic Detonation Propagation

Configuration*	Acceptor	Detonation Threshold (kbars)	Estimated Overpressure in Acceptor (kbars) Shock Induced	Fragment Induced	Sympathetic Detonation Prediction	Test
2A & 2B	MK 58	200	53	87	No	No
	WAU-17/B+	17	4	15	No	No
6A & 6B	MK 58	200	19	87	No	No
	WAU-17/B+	17	2	15	No	No
4A & 4B	WAU-17/B++	17	9	42	Yes	No
8A	WAU-17/B	17	19	51	Yes	Yes
9A	WAU-17/B (A1)	17	125	51	Yes	Yes
	WAU-17/B (A2)+++	17	9	45	Yes	Yes

*Configurations Refer To Fig. 1 nomenclature. Donor is WAU-17/B.

+MK 58 positioned as inhibitor.

++Four thicknesses of Aℓ positioned to simulate double side-walls of CNU-305.

+++Two thicknesses of Aℓ positioned to simulate top/bottom walls of CNU–305.

All of the airblast data at both test sites indicated that the fragments were still out ahead of the shockwave for all gage positions (overpressures down to ~4 kPa (0.6 psi)). This was evidenced by the fact that the blastwave records are preceded by signals produced by the shockwaves produced by the supersonic fragments. This result indicates that the shockwave energy associated with the fragments does not contribute to the blastwave out to these overpressure levels.

The airblast hazard range is defined as that distance from ground zero at which the overpressure level is 6.9 kPa (1.0 psi). The test data indicate that the airblast hazard range extends out to 34 m (110 ft) for a single SPARROW WAU-17/B warhead.

Airblast predictions were originally computed using the UTE (Unified Theory of Explosions) model.[2] These calculations included the effects of the warhead case mass, ground reflection factor for surface burst, and TNT equivalence for the base explosive based on airblast data taken from Reference 6. The cylindrical slope of the warhead with the associated length/diameter ratio effects and height of burst contributions were not included because they should not be important at the pressure regime (distances) of interest. The original prediction[1] indicates that the airblast hazard range extends out to 55 m (180 ft) for a single SPARROW WAU-17/B warhead. This result over-estimates the test result by 60%, not an acceptable prediction.

The difference between the measured and the predicted data is attributable to the effect/treatment of the case fragments. For example, the UTE model works well for the MK 82 bombs, airblast data and predictions correlate well, see reference 7. The MK 82 airblast records do not provide any indication that the fragments are out ahead of the blastwave below overpressures of 70 to 140 kPa (10-20 psi). The UTE model assumes that the fragment energy is fed back into the main shockwave, which appears to be the case for MK 82 but not true for SPARROW. Modifications to the UTE model to account for absense of the fragment contribution to the main blastwave provide a revised prediction of 35 m (115 ft) for the airblast hazard range; a very close comparison with the SPARROW test value of 34 m.

The difficulty in providing reasonable airblast hazard range predictions comes from the uncertainty of (not) including the case fragment contributions to the main blast wave without test data. The conservative approach is to include the case fragment effects and risk overestimating the magnitude of the airblast hazard range.

Table 2 compares the numbers of warheads required to exceed 6.9 kPa (1.0 psi) at selected ranges. These results are obtained by using the expression of the form $N = (R_N/R_1)^3$

where N = number of warheads
R_N = airblast hazard range for N warheads
R_1 = airblast hazard range for one warhead.

Table 2 Airblast Hazard Range Results

Hazard Range m(ft)	Original Prediction	Revised Prediction	Test Data
	Number of warheads that just satisfy airblast hazard criterion at specified range		
91 (300)	5	18	21
52 (500)	22	82	94
213 (700)	59	226	258
305 (1000)	121	658	752
381 (1250)	335	1284	1468

FRAGMENT HAZARD

The fragment recovery test program was conducted at NWC, China Lake, CA to verify/extend/update fragment hazard predictions presented in reference 1. Three single bare warheads were detonated. A single recovery operation was conducted after the three detonations.

A thorough survey of the recovery area yielded an adequate fraction of the fragments produced to define the fragment hazard range.* All collected fragments were identified, surveyed in place, weighed, and shipped to NSWC, Dahlgren, VA to have fragment presented area measurements made on an icosohedron gage.

The survey data provided the areal distributions of the fragments in the recovery area. The fragment mass and area measurements provided average values and distributions for these parameters to be used in trajectory calculations. The drag coefficient used for the SPARROW fragments was the variable drag coefficient (with Mach number) for shell fragments given in reference 8. Warhead arena data provided the initial velocities and ejection angles.

Trajectory calculations (Program TRAJ - Reference (2)) were used to evaluate the energies of the SPARROW fragments at their surveyed impact locations. Those surveyed fragments that were evaluated to have impact energies greater than or equal to 80 J were assessed to be hazardous. Those surveyed fragments with impact energies less than 80 J were assessed to be non-hazardous. In this way, separate areal distributions were developed for

*The fragment hazard criterion requires that these be less than one hazardous fragment per 55.7 m^2 (600 ft^2). A fragment is considered hazardous when it has an impact energy of 80 J (58 ft-lb) or greater. The fragment hazard range is defined as that range beyond which the fragment hazard criterion is satisfied.

hazardous and non-hazardous fragments. The fragment hazard range was determined from the areal distribution for hazardous fragments. The results indicate that the SPARROW fragments are not hazardous beyond 490 m (1600 ft). At this range 59 radially aligned warheads are required to contribute their share of fragments (without interaction effects) in order to exceed the hazardous fragment areal density criterion.

Original predictions for the fragment hazard range using trajectory calculations based on limited arena data indicated that the SPARROW fragments were hazardous all the way out to the computed maximum range of 1070 m (3500 ft). The fragment survey data showed that the computed maximum range based on the limited arena data was in error. The original predictions[1] also indicated that only twelve or more radially aligned warheads (neglecting fragment interactions from separate warheads) were required to exceed the hazardous fragment areal density criterion at 1070 m.

The limited arena data used for the original predictions were updated with the fragment characterization results obtained from the present test program. Basically, a single value for the parameter $C_D\bar{A}/m$ (where C_D = drag coefficient, $\bar{A}$ = average drag area, and m = fragment mass) used for the original predictions was replaced with separate definitions for C_D, $\bar{A}$, and m. Using the updated input values for these parameters, revised predictions were made using the same methods employed for the original prediction (described in Appendix A of reference 1). The revised prediction gave the following result: 52 radially aligned warheads are required to exceed the hazardous fragment areal density criterion at 490 m. The revised prediction compares quite favorably with the test result. The two predictions and the test result are summarized in Table 3 below.

Table 3 Fragment Hazard Range Comparisons

	Original Prediction	Revised Prediction	Test Result
Warheads Required	12	52	59
Fragment Hazard Range, m (ft)	1070(3500)	490(1600)	490(1600)

The test result indicates that 10% more warheads satisfy the hazardous fragment areal density criterion at 490 m than the revised prediction.

Table 4 provides hazard range estimates* for numbers of warheads less than the critical value 59 (the test value). The maximum fragment hazard range is 490 m for any number of warheads 59 or greater.

*These results (rough estimates) are based on cylindrical divergence (including the beam spray) using straight line trajectories to areal densities.

TABLE 4 FRAGMENT HAZARD RANGES

NUMBER OF WARHEADS	FRAGMENT HAZARD RANGE, m (FT)
1	45 (145)
2	65 (210)
4	90 (295)
8	125 (420)
10	145 (470)
11	150 (490)
12	155 (515)
15	175 (575)
22	210 (695)
30	245 (810)
40	285 (940)
50	320 (1050)
58	345 (1130)
59 (OR MORE)	490 (1600)*

*BASED ON FRAGMENT GROUND PICKUP DATA ANALYSIS. ALL OTHER FRAGMENT HAZARD RANGES ARE ESTIMATES BASED ON STRAIGHT-LINE TRAJECTORY CALCULATIONS. ALL CALCULATIONS WERE PERFORMED IN ENGLISH UNITS (FT).

FINAL COMMENTS

Replicate test shots provided quite similar results for airblast data and acceptor warhead/rocket motor responses. The revised airblast prediction model calculations compare quite well with the SPARROW airblast data.

For nose-to-tail missile stacking configurations, in which warheads are aligned side by side with rocket motors, detonation did not propagate to acceptor rocket motors and warheads. For the warhead-to-rocket-motor spacing representing separation distances inside the USAF CNU-305 shipping container, the violence of the acceptor rocket motor and warhead reaction does contribute significantly to airblast (Tests 2A and 2B). For the warhead-to-rocket-motor spacing corresponding to the USAF munitions transport trailer and the proposed high density rack separation distances, the acceptor rocket motor reaction does not contribute significantly to the airblast and the acceptor warhead remains intact (Tests 6A and 6B).

For side-by-side warheads, detonation did not propagate to an acceptor warhead in the test simulation corresponding to an adjacent USAF CNU-305 shipping container (Tests 4A and 4B). This test result was not predicted by the model. The four thin aluminum plates are a candidate minimal shield for inhibiting sympathetic detonation between warheads aligned side by side. Detonation did propagate in the test configuration simulating adjacent acceptor warheads either within or in an upper/lower USAF CNU-305 shipping container (Test 9A). Detonation did propagate to an adjacent acceptor warhead at a distance corresponding to the separation distances in the USAF munitions transport trailer and in the proposed high density rack design (Test 8A). It should be noted that the conclusions for a non-propagation test response are based on two consecutive non-propagation test responses that agree with the simplistic predictive model (except for the surprising Tests 4A and 4B results).

The far-field fragment collection conducted on this program has pointed up several deficiencies in the methodology of using "near-field" arena test data to describe the far field fragments. These deficiencies include:

(1) The dependence on an average value of $C_D \bar{A}/M$ (as determined from arena data) is not adequate for deriving fragment input conditions for trajectory calculations.

(2) The recovered fragments indicate a much larger dispersion with respect to azimuth angle than the beam spray angle determined from arena data would indicate. Thus beam spray angle (and associated ejection angles) as reported from arena test results cannot be used to define limits for fragment impact locations in the far field.

The standard airblast prediction techniques overestimate airblast ranges because of the manner in which they handle fragment energies. For weapons, such as SPARROW, the fragments remain ahead of the shockwave out to low pressures.

The maximum hazard range for one WAU-17/B warhead is 34 m (110 ft) for airblast and 45 m (145 ft) for fragments. The maximum fragment hazard range is 490 m (1600 ft) for 59 or more warheads. Fifty-nine warheads exceed the airblast hazard criterion at 131 m (430 ft). At 490 m, more than 3077 warheads are required to exceed the airblast hazard criterion. The hazard range (490 m) for the SPARROW WAU-17/B warhead is controlled by the fragment hazard criterion (and not the airblast) for 59 or more warheads (up to 3077). Above 3077 warheads, the hazard range is controlled by airblast.

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NOVEL APPROACHES TO DEMILITARIZING BURSTERED CHEMICAL MUNITIONS

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TWENTY FIRST DoD EXPLOSIVES SAFETY SEMINAR

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Novel Approaches to Demilitarizing Burstered Chemical Munitions

Introduction:

The US Army Toxic and Hazardous Materials Agency (USATHAMA) research and development effort will provide an integrated system to demilitarize the chemical munitions stockpile. The chemical stockpile includes mines, rockets, bombs, agent containers and projectiles (Fig 1) in varying numbers at several storage sites. The munitions containing explosives, which are of concern in this research and development program are the projectiles. The demilitarization of burstered projectiles is being studied in terms of single items and as palletized or boxed munitions.

Technical Approach:

The purpose of a seven year effort is to develop an inherently safe system which will provide at least a thirty percent savings in the cost of demilitarizing the chemical stockpile when compared to present technology (Fig 2). The present technology is called the baseline and is based primarily on reversing the assembly process.

The cost of demilitarization with baseline technology will be compared to that of new technology over the life of the demilitarization operation; this is called life cycle cost (Fig 3). The life cycle costs based on actual per site inventories include facility costs, capital costs, operational costs and for the R&D technologies a one time development cost. Each of the items include costs pertaining to safety considerations. The life cycle costs are used not only to compare competing technologies but to optimize systems throughput size and configurations. The life cycle costs will ultimately determine the demilitarization system configuration.

The R&D effort is presently in the prototype phase (Fig 4). During Phase I, two systems emerged for further study in Phase II: fracture of cryogenically cooled munitions (Fig 5) and penetration and access of munitions by thermite or explosively propelled projectiles (HAC, Fig 6).

Discussion of Cryogenic Fracture:

The cryo-fracture pretreatment (Fig 7) embrittles the steel allowing it to shatter with reduced applied force. The cryo-pretreatment also freezes the agent, which helps contain the agent and limits agent contamination.

As envisioned, the munitions are fractured by a press creating an unconfined feed to a rotary kiln furnace (Fig 8). The furnace deactivates the explosive, incinerates the agent and detoxifies the metal.

Robotics are used in the unpack/repack operations to minimize human contact with leaking munitions (Fig 9). The munitions may be reconfigured from their storage configuration to racks which can be placed in a bath of liquid nitrogen (Fig 10). The robot for this operation is a gantry overhead robot. The munitions placement in the cryo-bath is computer controlled. The computer keeps track of where a rack is located, how long it has been cooling and turns control

of harvesting the rack over to a second gantry robot upon completion of the cooling time required for the munition type.

The harvested munitions are placed in an airlock where they can be reached by a pedestal robot (Fig 11). This pick and place robot removes the munitions from the rack in the airlock and places them in the tooling of the press.

The tooling for fracturing the munitions is within an explosive containment and is different for each munition configuration (Fig 12). The explosive containment texture consists of two sections, the top fitting over the bottom section (Fig 13). The explosive containment protects the press from the possible blast pressure and shell fragmentation of a detonation. An impulse plate assembly containing crushable honeycomb material protects the piston from the blast. When both halves of the chamber are together the munition has been fractured, insuring a fail safe process. The fragments fall through a chute to the furnace.

A remote maintenance capability will be designed into the cryogenic equipment. This is achieved by modularizing the production equipment, so that maintenance can be accomplished by the robots. Remote maintenance will reduce manned entries into toxic and explosive areas.

Discussion of Heat Activated Chemicals:

The term HAC is an acronym from heat activated chemical and refers to the early concept of initiating thermite using the heat of the furnace (Fig 14), the object being to unconfine the agent cavity of the munitions inside a furnace. Because of their flexibility, explosively formed projectiles (shaped charges) replaced thermite as the means of accessing the chemical munitions (Fig 15).

The HAC process, as presently envisioned (Fig 14), is an integrated system using robotics to place a HAC Kit on the munition pallets or boxes. This increases the safety of handling potential leaking munitions and explosives. If life cycle cost analysis suggests the need to disassemble pallets, the robot will perform this function. The Kit will have an interrupt between the primary charge, i.e. blasting cap, and the explosive train, i.e., primacord thus affording the same safety as a fuze. The munitions will pass through an airlock to a chamber in an explosive containment room (ECR). The explosive circuit will be completed after the chamber is sealed, and the train initiated. The agent will be drained to an agent incinerator, the explosive will be deactivated and the metal parts decontaminated.

Variations on the above scenario are being studied (Fig 16). One variation would substitute chemical deactivation and decontamination for thermal decon. In another variation, the burster in the projectile can be missed by explosively propelled projectiles and, after chemical decon of the agent cavity, the burster is removed by conventional means. The options are driven by safety considerations. To insure the equal safety of each option, cost penalties are incorporated into the life cycle costs based on failure analysis trees. The life cycle cost studies will eventually determine the ultimate HAC concept, hence the system with inherent safety features.

Hazard Analysis:

Hazards analysis for the cryogenic fracture and the Heat Activated Chemical Demil Systems is an integral part of the program. The design contractor has completed a preliminary hazards analysis on both demil systems and is continuing to provide detailed analysis to support the systems analysis and life cycle cost efforts. An independent contractor is also performing hazards analysis studies in support of the project.

The hazards analysis contributes directly to the design of the processes by providing a comparison of the design options to increase the safety and availability of a system.

A functional flow diagram of the process is developed (Fig 18) and indices are established for the individual process steps. The possible events for these indices are tabulated on a form (Fig 19). The events are assigned a severity and a probability, based upon system data. These factors determine the risk category. At this point a preliminary risk profile can be developed to graphically represent the risks for comparison to other systems (Fig 20).

A fault tree for each major event is created to describe the steps leading to that event (Fig 21). The event can be the result of a single fault (or) or the result of a combination of faults (and). To make a system safe, a combination of safeguards in the form of redundancy are added to require multiple faults leading to an event (Fig 22).

To provide a quantitative representation of the fault tree, a computer reduction is made based on the probability of the individual faults. By graphically depicting the cumulative probability of the event versus frequency of occurrence, the increased safety of the options can be compared (Fig 23). The further apart two options are the greater the effects of the redundancy, hence the greater reduction in frequency the greater the return on the investment.

Progress to Date:

The cryogenic system has completed testing through bench scale design of Phase II (See Fig 4). A press is able to fracture burstered projectile casings. Work with simulant explosives showed pressures exerted on the explosives should pose no unsafe condition (Fig 24). Tests on burstered munitions have confirmed the press design.

A prototype intergrated system has been constructed at GA Technologies (Fig 25). This test bed incorporates an unpack robot, cryogenic bath, pick and place robot and a press. The integrated system will provide throughput data on simulant rounds, and assist in identification of unanticipated failure modes.

The robotic systems data can be used for HAC systems analysis.

The initial HAC tests successfully demonstrated the repeatability and controlability of explosively propelled projectiles (EP^2) in accessing agent cavities (Fig 26).

The objective to penetrate burster wells and bursters with EP^2's was studied from several aspects (Fig 27). The Held's Effect predicts the detonation of explosives as a function of velocity and projectile diameters in shaped charges (V^2D). Tests thus far have verified that bursters do not detonate from shock initiation.

An accelerated thermal burn is initiated by the EP^2's. The limits of the various EP^2's on the various munitions were systematically established.

The effects of casing unconfinement on burster detonation (drained projectiles) and thermal burns were also characterized.

Two examples of the early burster tests are shown in Figures 28 through 32. Figure 28 shows a large shaped charge 20.5 grams RDX firing into a mortar of one forth of an inch wall thickness. Figure 29 shows that the primary explosive in the fuze has detonated but not the secondary explosive in the munition. A second charge penetrating through the burster started a burn, which in this tetryl burster continued to completion. Figure 32 shows a simular event in a 105mm projectile.

Test with a single 20.5 gram charges directly hitting the burster perforated the casing and the bursters but the explosive was not completely consumed.

Tests results on cast Comp B bursters were different from those of pressed tetryl or tetrytol. The Comp B bursters have a larger diameter than bursters of tetryl or tetrytol. Comp B bursters when penetrated by shaped charge jets many times burned violently unconfining the burster well (see Figure 33). It was observed that the explosive in the unburned bursters was pulverized.

Tests were done in an improvised furnace with confined bursters in unconfined projectile casings. Longitudinal movement of the burster well as well as its expansion was noted (see Figure 34). It was concluded that the rapid burns were the worst case for operational design, although the facility would contain a detonation. Secondly, the increased surface area fractured explosive as well as the pressure increase the burning rate.

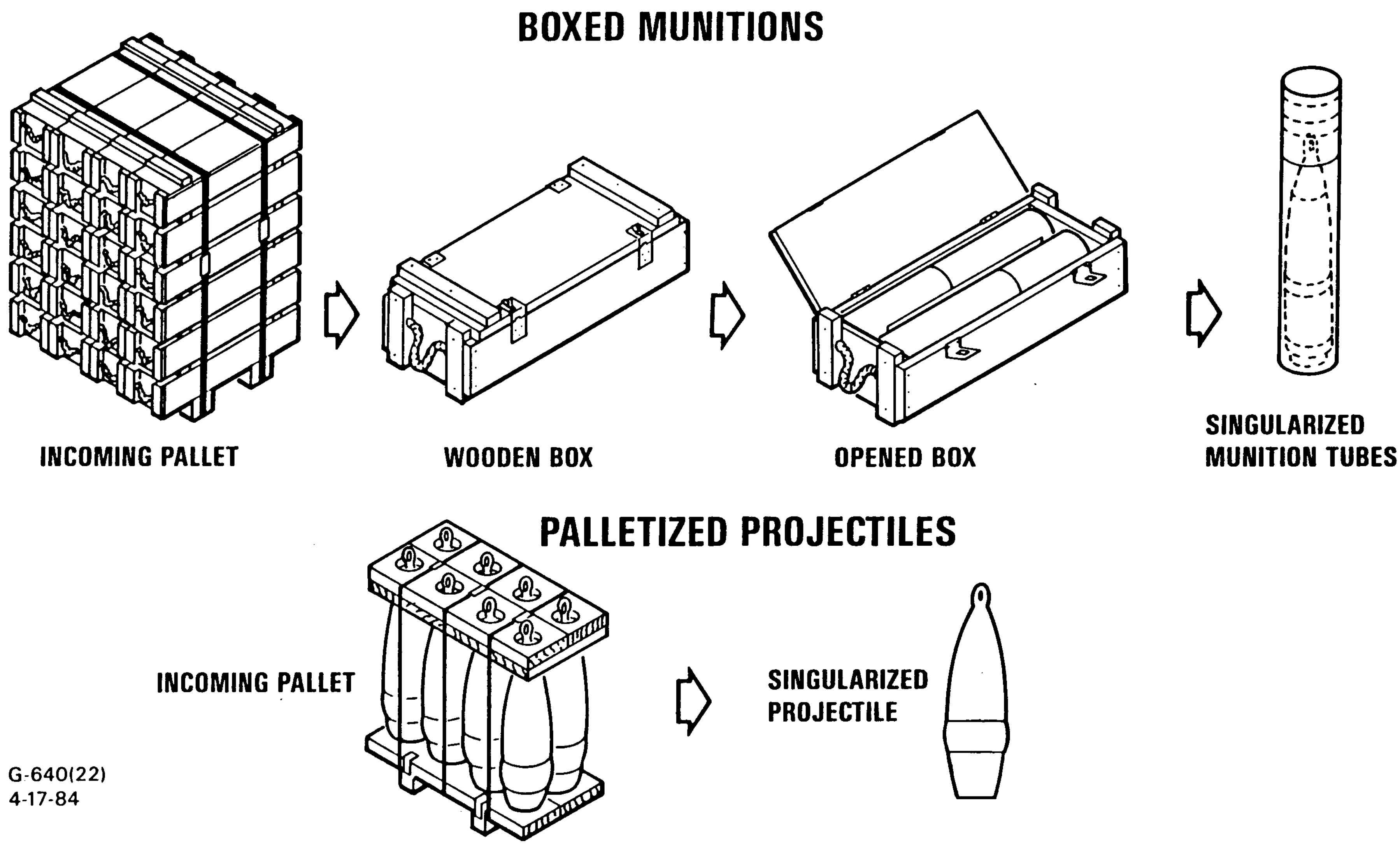
Future Plans:

After the integrated cryogenic tests, the press will be relocated to a test site capable of explosive testing. The press will fracture a statistical number of cryogenically cooled bursters. The explosive containment will be challenged after the parametric statistical tests to verify the design.

The HAC test will attempt to reduce the concept options by January 1985. A prototype chamber will be built and prototype kits on simulant munitions will be tested summer 1985.

In summary, it is felt the present concepts provide greater safety in handling agent and explosives than the current processes.

Also testing to date continues to demonstrate the potential to design these processes without risk of explosive detonation in either system.



BOXED MUNITIONS
INCOMING PALLET
WOODEN BOX
OPENED BOX
SINGULARIZED
MUNITION TUBES
PALLETIZED PROJECTILES
INCOMING PALLET
SINGULARIZED
PROJECTILE
G-640(22)
4-17-84

FIGURE 1

PROGRAM OBJECTIVES

- DEVELOP TECHNICALLY SOUND, POLITICALLY AND SOCIALLY ACCEPTABLE, OPERATIONALLY AND ENVIRONMENTALLY SAFE TECHNOLOGY
- SIGNIFICANTLY REDUCE (>30%) COST OF DEMIL
- COMPLETE DEVELOPMENT IN 5 – 7 YEARS

FIGURE 2

LCC METHODOLOGY

- FACILITY COST - FOR EACH FUNCTION DEFINE FT^2 AND NEED FOR EXPLOSIVE CONTAINMENT; USE STANDARD INDICES FOR CONVERSION
- CAPITAL COST - FOR EACH AREA IDENTIFY EXACT PIECE OF EQUIPMENT AND COST; ADD 25% DESIGN COST FOR EACH FACILITY
- OPERATIONAL COST - FOR EACH CATEGORY OF MUNITIONS IDENTIFY NUMBERS OF PERSONNEL, AMOUNT OF MATERIALS, SUPPLIES ON AN ANNUAL BASIS;
  - USE STANDARD INDICES FOR CONVERSION
  - USING THROUGHPUT RATES DEGRADED FOR SYSTEM UNRELIABILITY AND MAINTAINABILITY
  - CALCULATE PRODUCTION DURATION AND MULTIPLY BY ANNUAL COSTS
  - ADD NON-PRODUCTIVE PERIODS FOR EQUIPMENT INSTALLATION, SYSTEMIZATION, TRAINING, CHANGE-OVER, SHUTDOWN
- R&D COST - ADD ONE-TIME COSTS OF DEVELOPMENT OF EACH MECHANICAL AND AGENT DESTRUCT TECHNOLOGY THROUGH LAB AND BENCH SCALE PLUS AN INTEGRATED SYSTEM PILOT PLANT. (SYSTEM PILOT PLANT NOT REQUIRED ON BASELINE)

FIGURE 3

APPROACH

CONCEPT PHASE

- IDENTIFY TECHNICAL AREAS
- BROAD-BASED LITERATURE AND INDUSTRY SURVEY
- CREATIVE CONCEPT FORMULATION
- COMPARATIVE SYSTEM ANALYSIS: TECHNICAL AND COST

PROTOTYPE PHASE

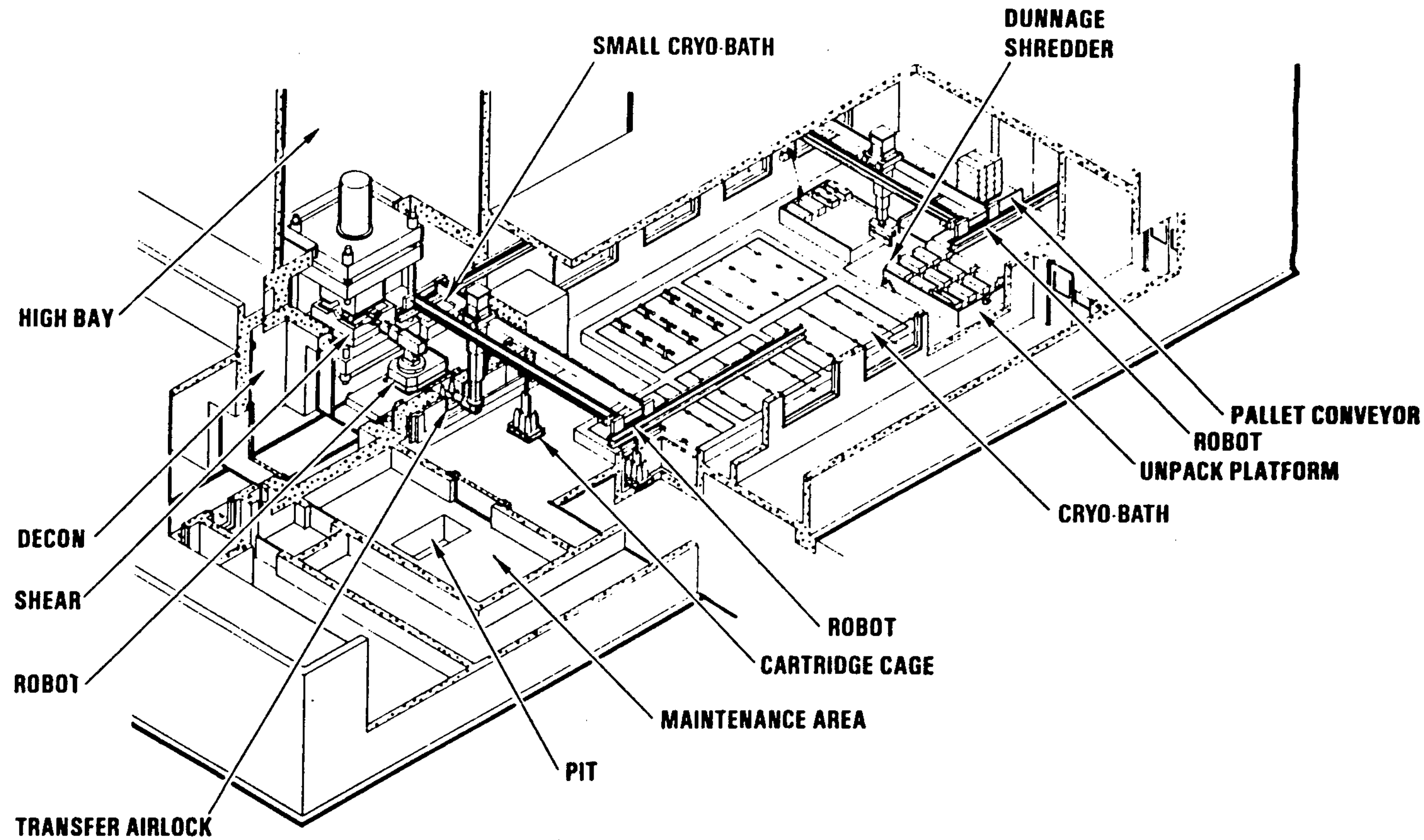
- LAB SCALE PROTOTYPE DESIGN
- PROOF-OF-PRINCIPLE TESTING
- BENCH SCALE DESIGN
- PARAMETRIC TESTING
- SYSTEM ANALYSIS: PILOT TECHNOLOGY SELECTION

PILOT PHASE

- FACILITY CONTRUCTION
- PILOT PROCESS DESIGN, FABRICATION, ASSEMBLY
- PRE-OPERATIONAL CHECK-OUT, PERSONNEL TRAINING
- PILOT TESTING
- PRODUCTION PLANT TECHNICAL DATA PACKAGE

FIGURE 4

CRYO-FRACTURE PROCESS LINE



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1-4-84

FIGURE 5

HAC PROCESS LINE

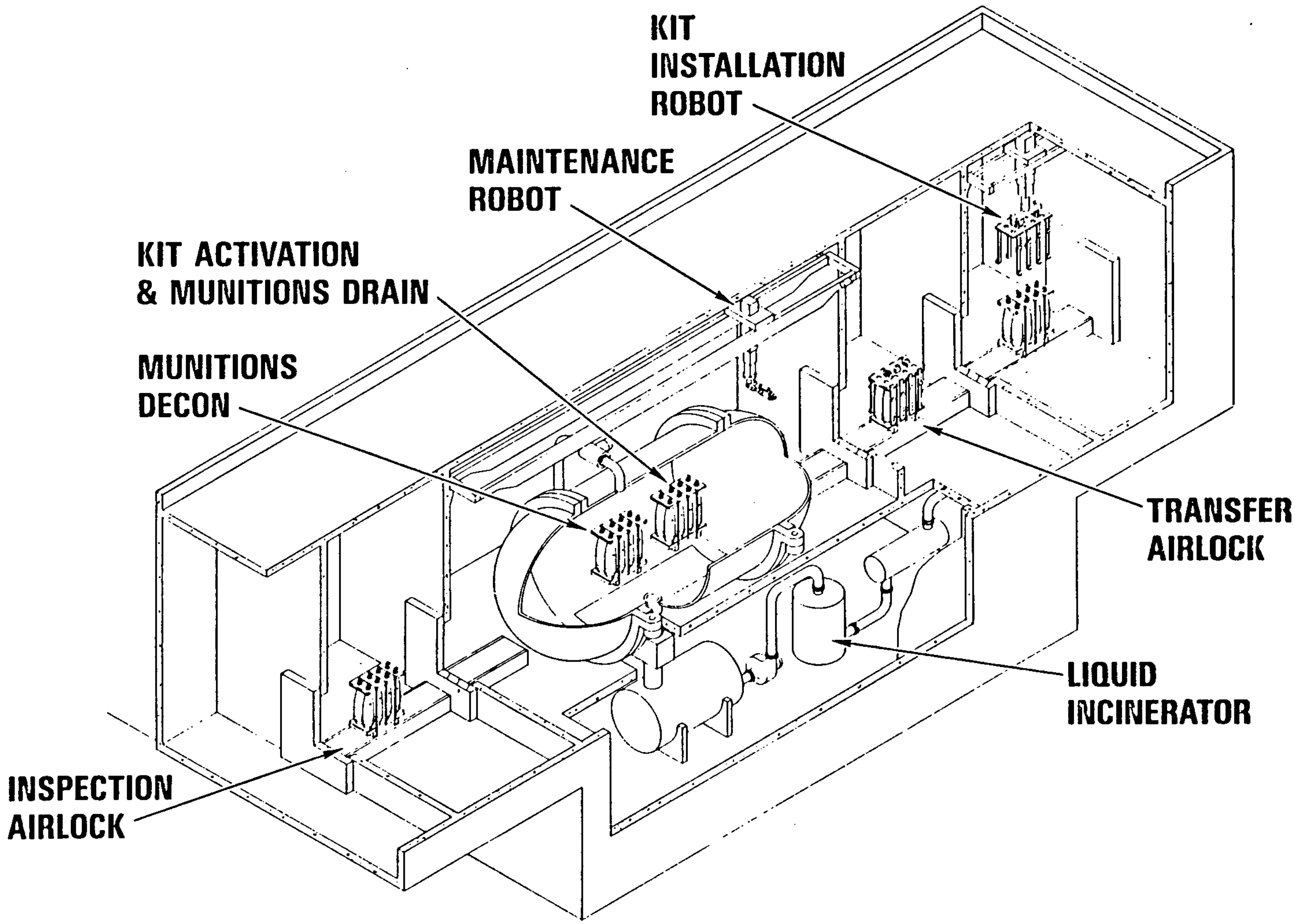
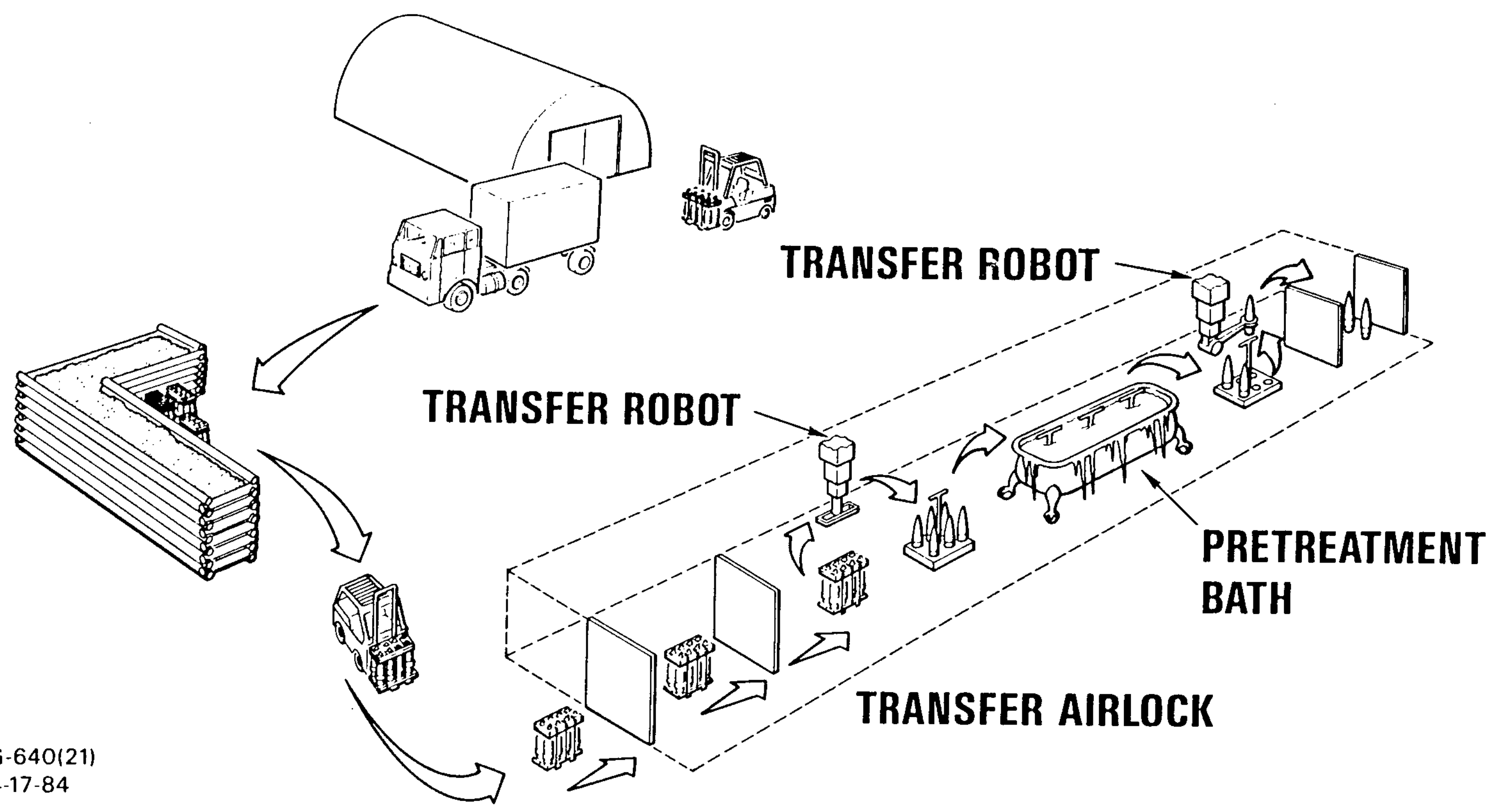


FIGURE 6

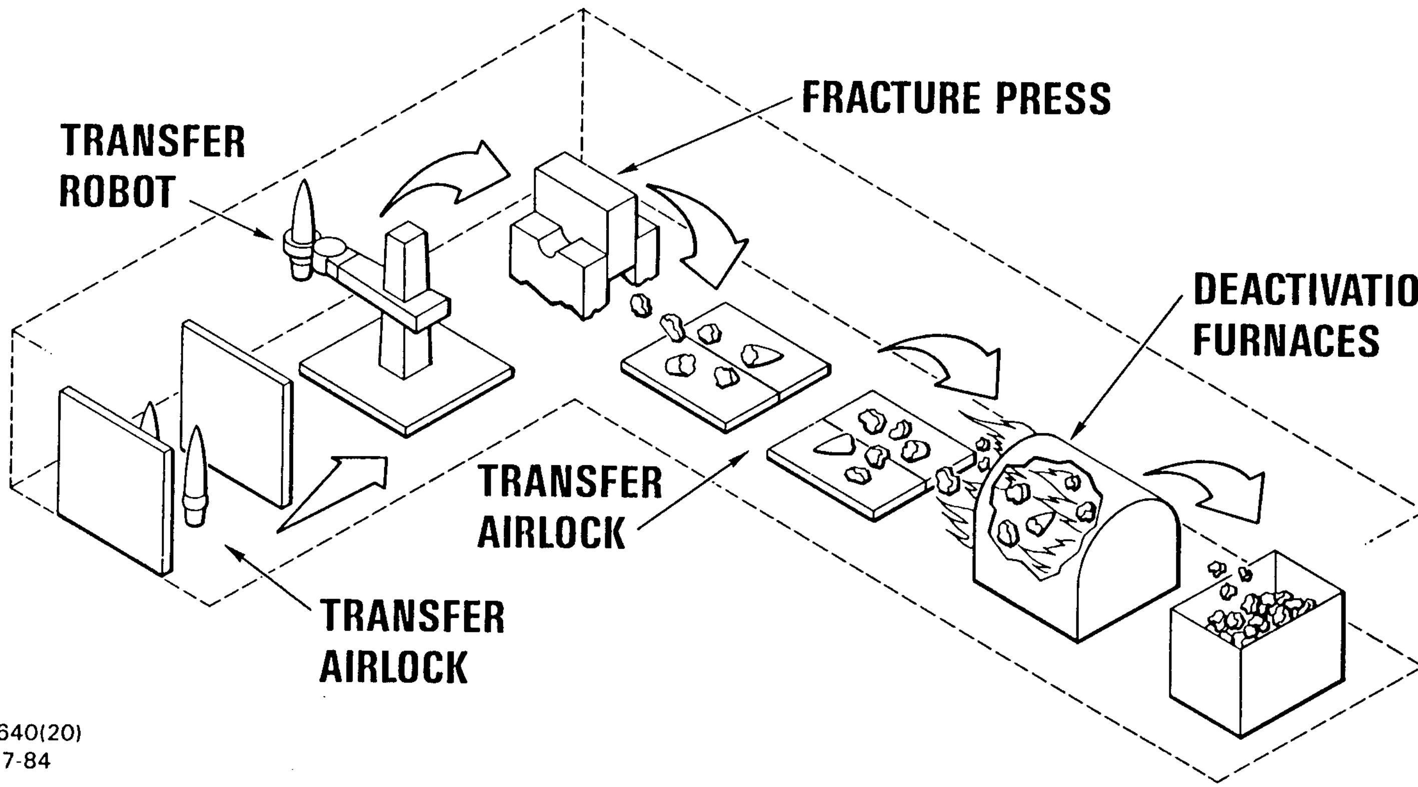
CRYO-PRETREATMENT PROCESS



G-640(21)
4-17-84

FIGURE 7

CRYO-FRACTURE PROCESS



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4-17-84

FIGURE 8

ROBOTIC UNPACKING

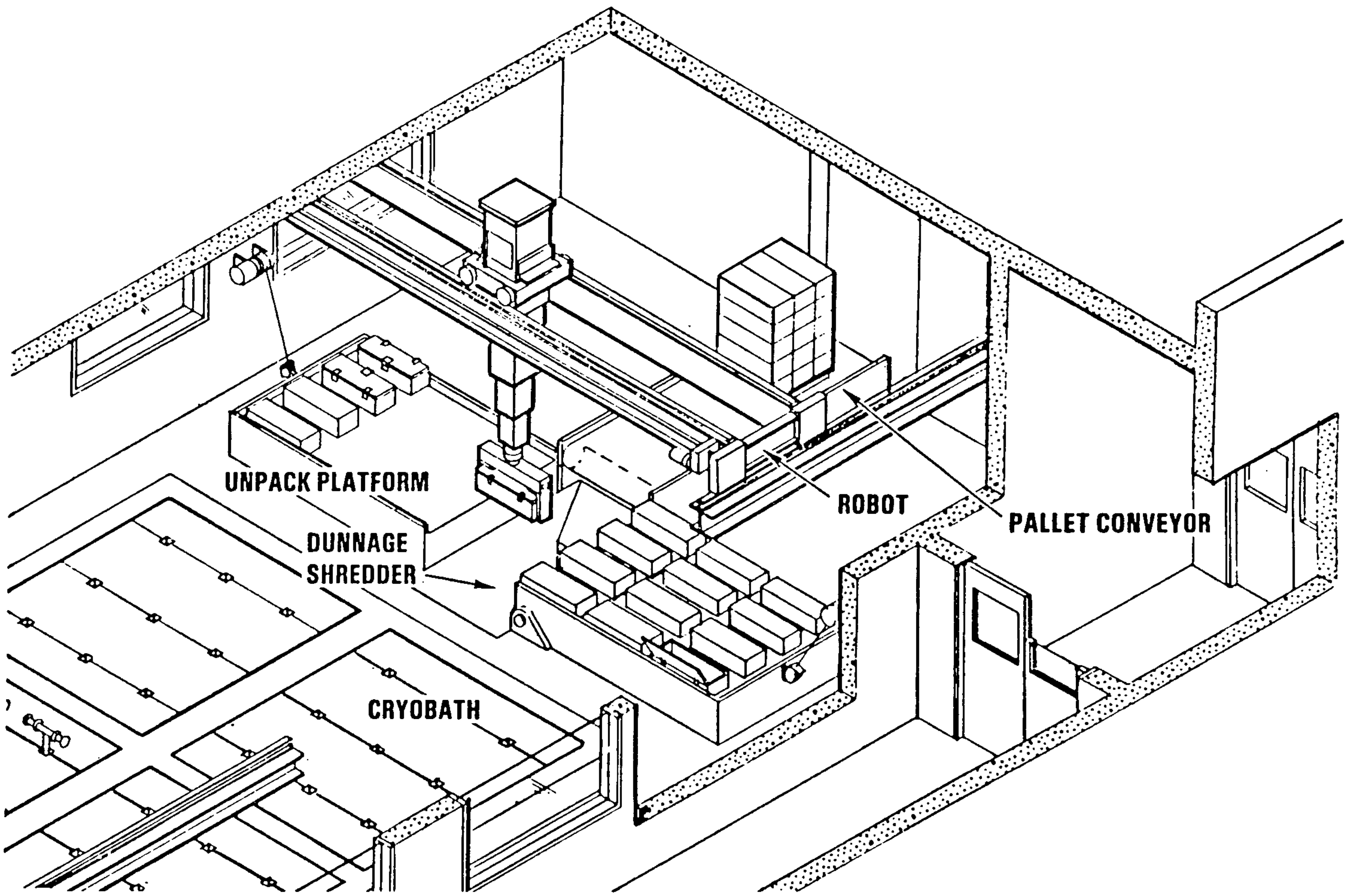

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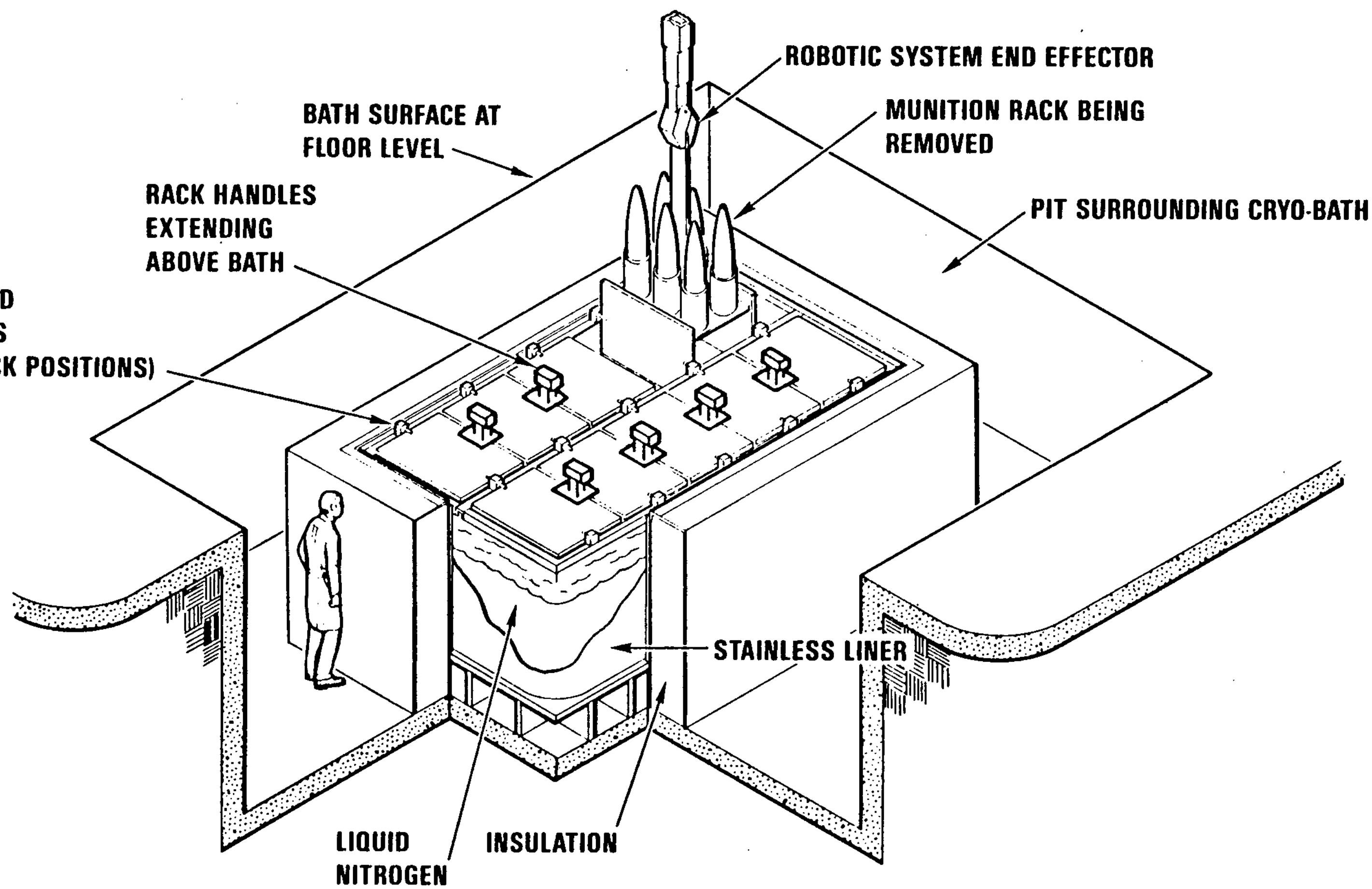
FIGURE 9

LIQUID NITROGEN CRYO-BATH



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5-2-84

FIGURE 10

CRYO-FRACTURE PRESS WITH ROBOTIC FEED

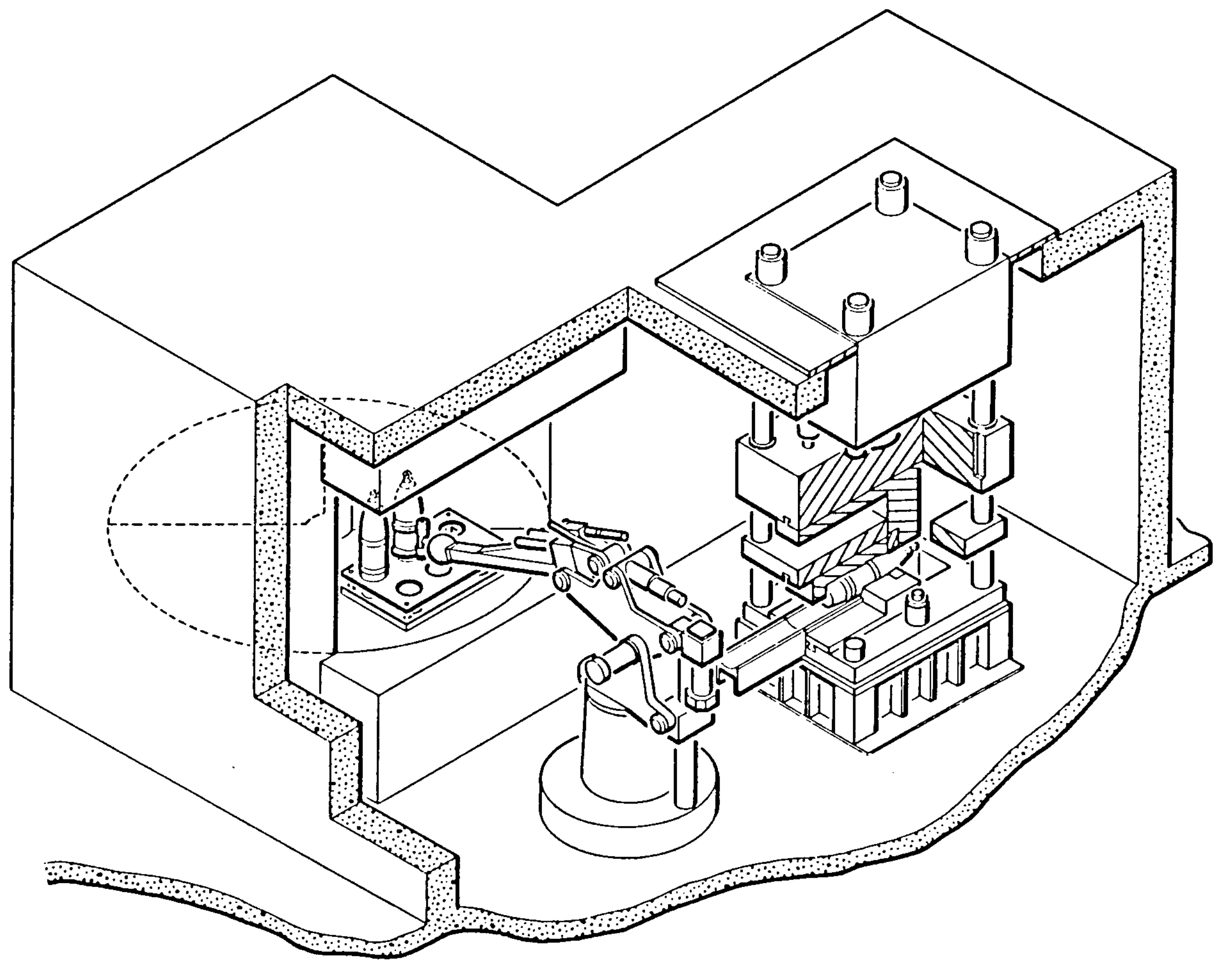


FIGURE 11

CRYO-FRACTURE PRESS
WITH DIE-SET
EXPLOSIVE CONTAINMENT

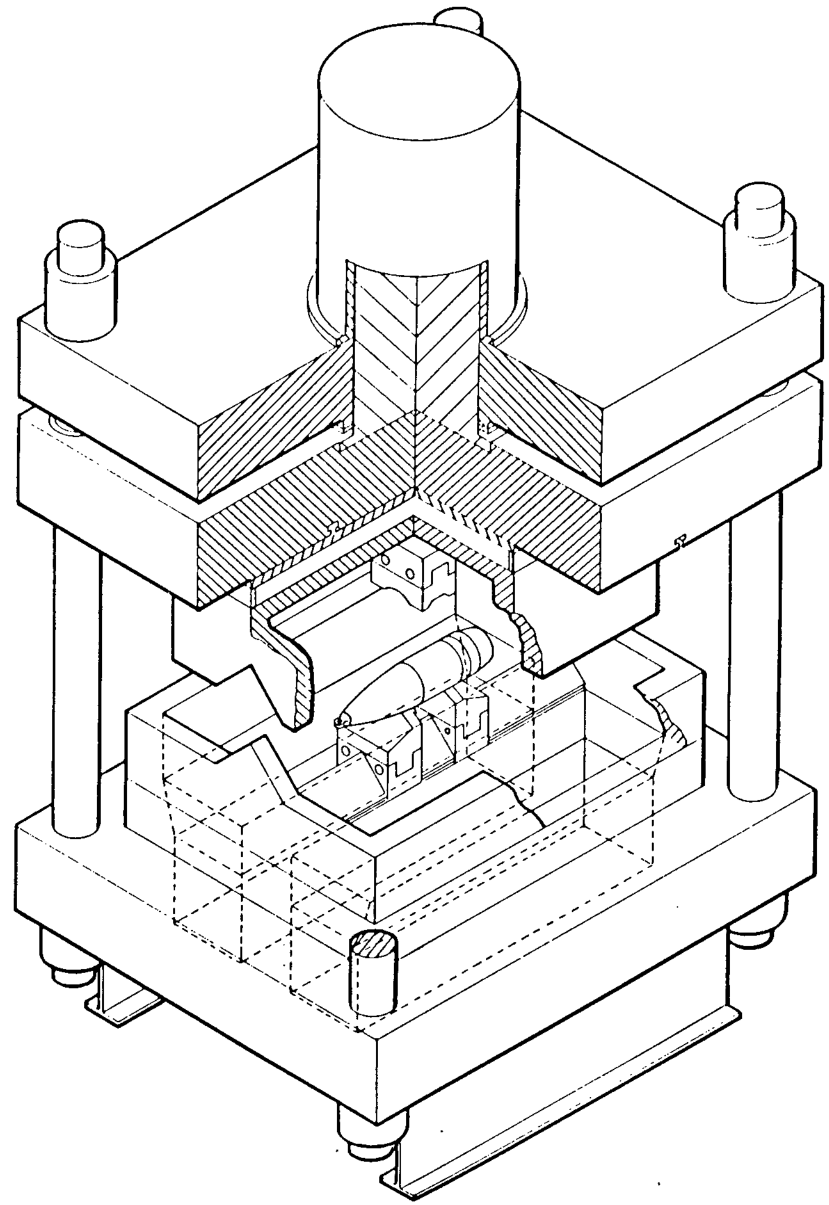
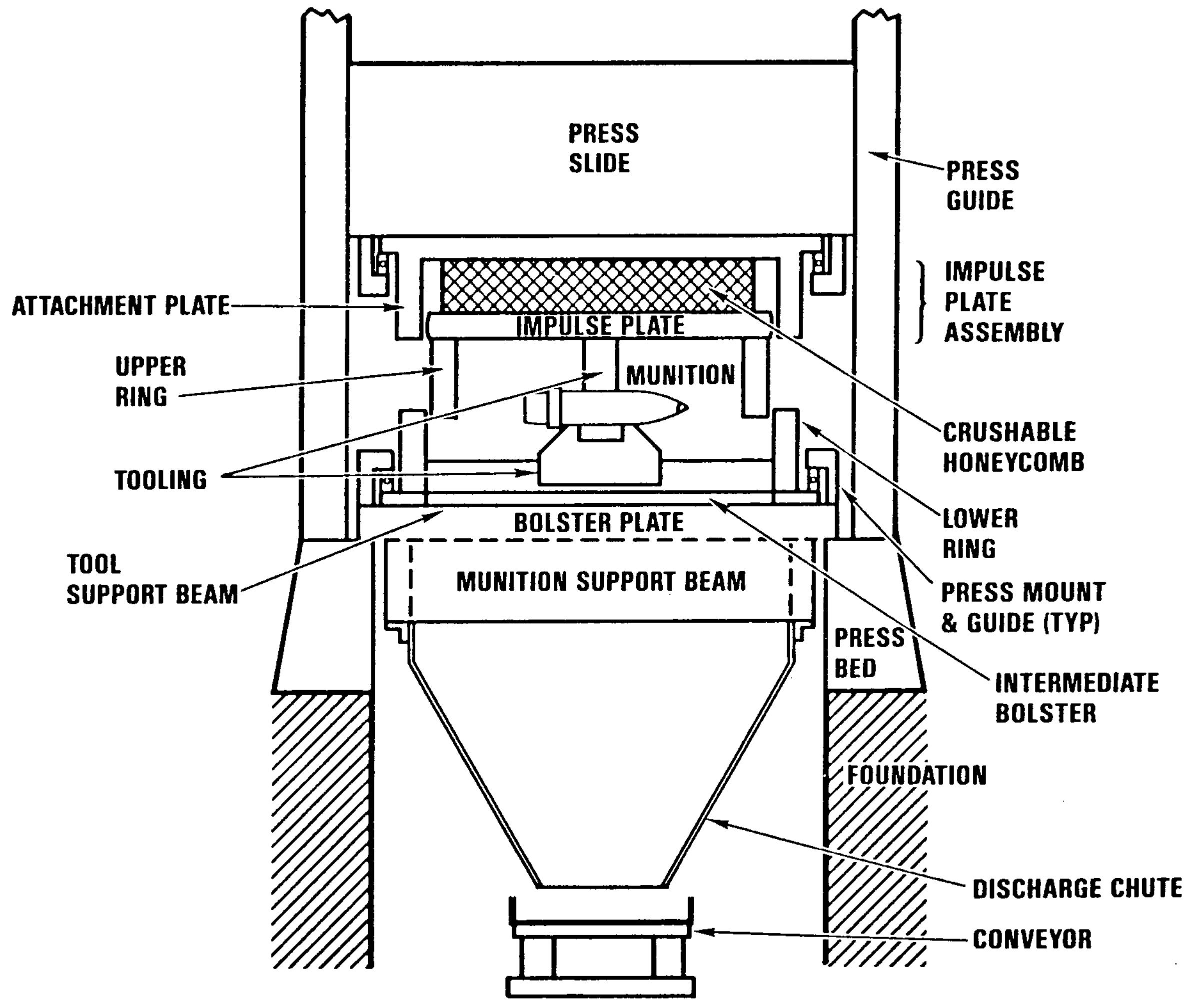


FIGURE 12

CRYO-FRACTURE
EXPLOSIVE CONTAINMENT CHAMBER



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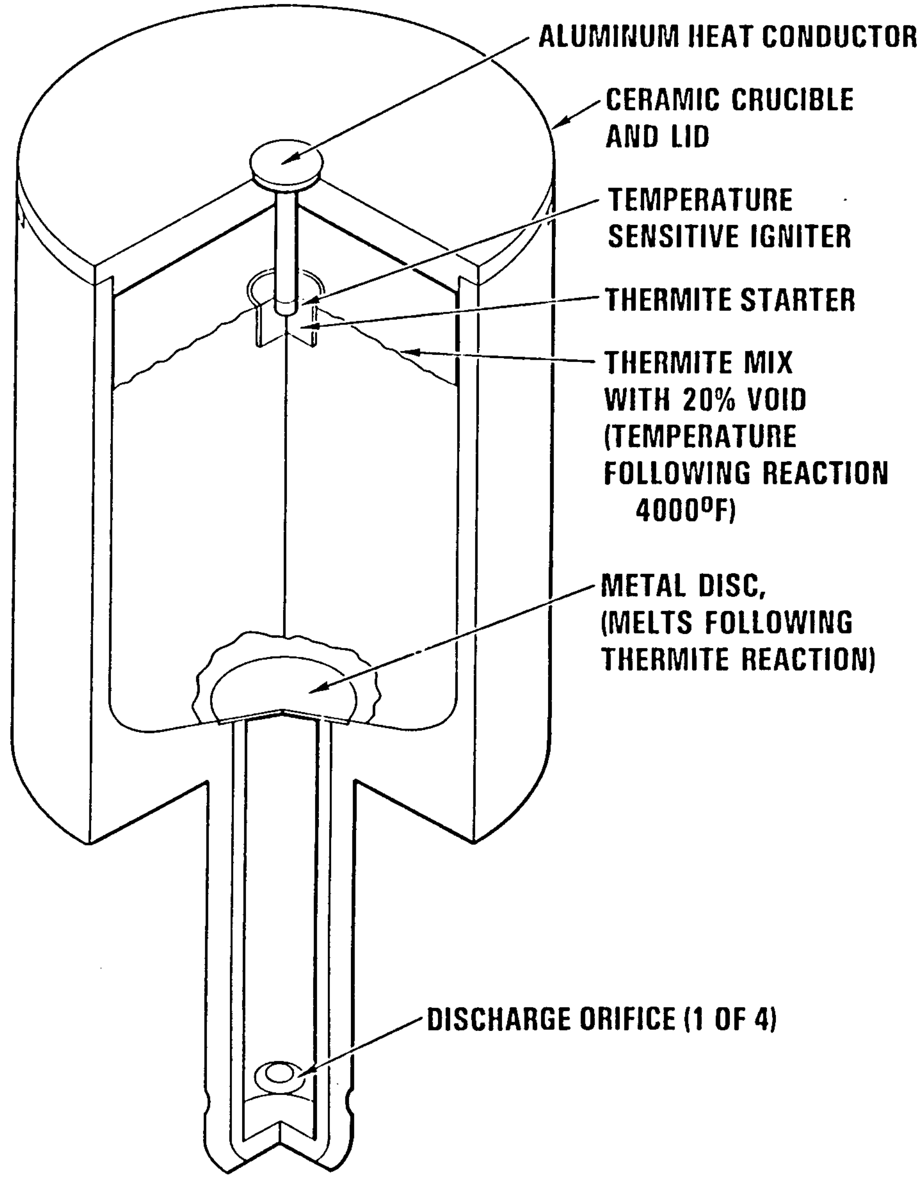
5-2-84

FIGURE 13

THERMITE KIT



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11-1-83

FIGURE 14

SHAPED CHARGE CONCEPT
PALLET OF 8 155 MM PROJECTILES

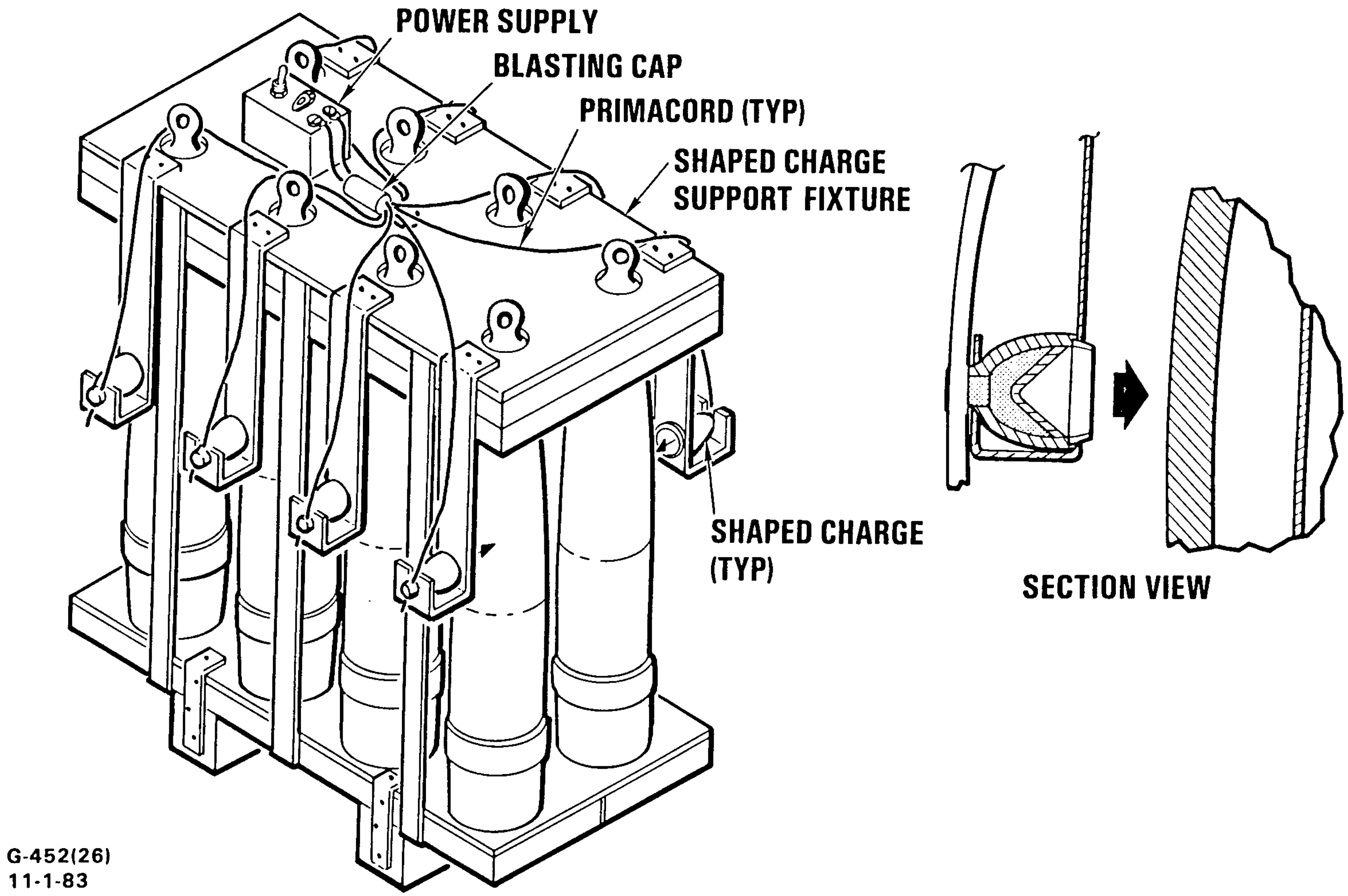
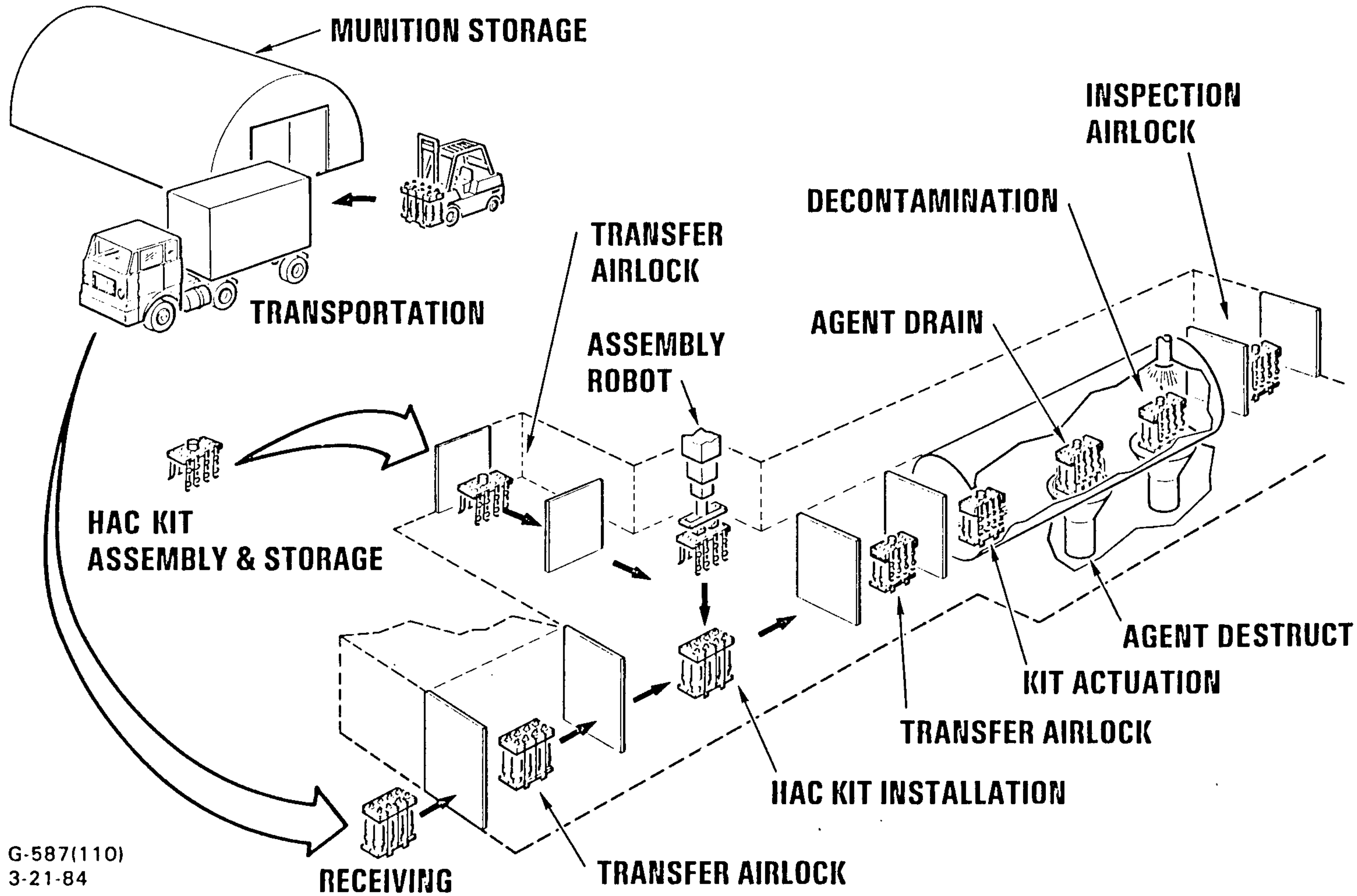


FIGURE 15

HAC DEMIL PROCESS



FIGUPE 16

GA Technologies

HAC DISASSEMBLY PROCESS

KNOWLEDGE GAPS

- ACCESS LOCATION AND HOLE SIZE FOR DRAIN AND DECON
- ABILITY TO ACCESS BURSTERED MUNITIONS
- ABILITY TO ACCESS BOXED MUNITIONS
- REMOTE, ROOM TEMPERATURE INITIATION
- KIT PERFORMANCE
- SHAPED CHARGE BLAST EFFECTS

- RELATED SYSTEMS ISSUES e.g. DECON
- SENSITIVITY OF LOW ORDER EXPLOSIONS
- ACCESS HOLE CONFIRMATION

DESIGN ISSUES

- DESIGN OF ACCESS CHAMBER FOR:
  - SHAPED CHARGE DETONATIONS
  - BURSTER LOW ORDER EXPLOSIONS
- ROBOTIC PLACEMENT OF SHAPED CHARGE KITS

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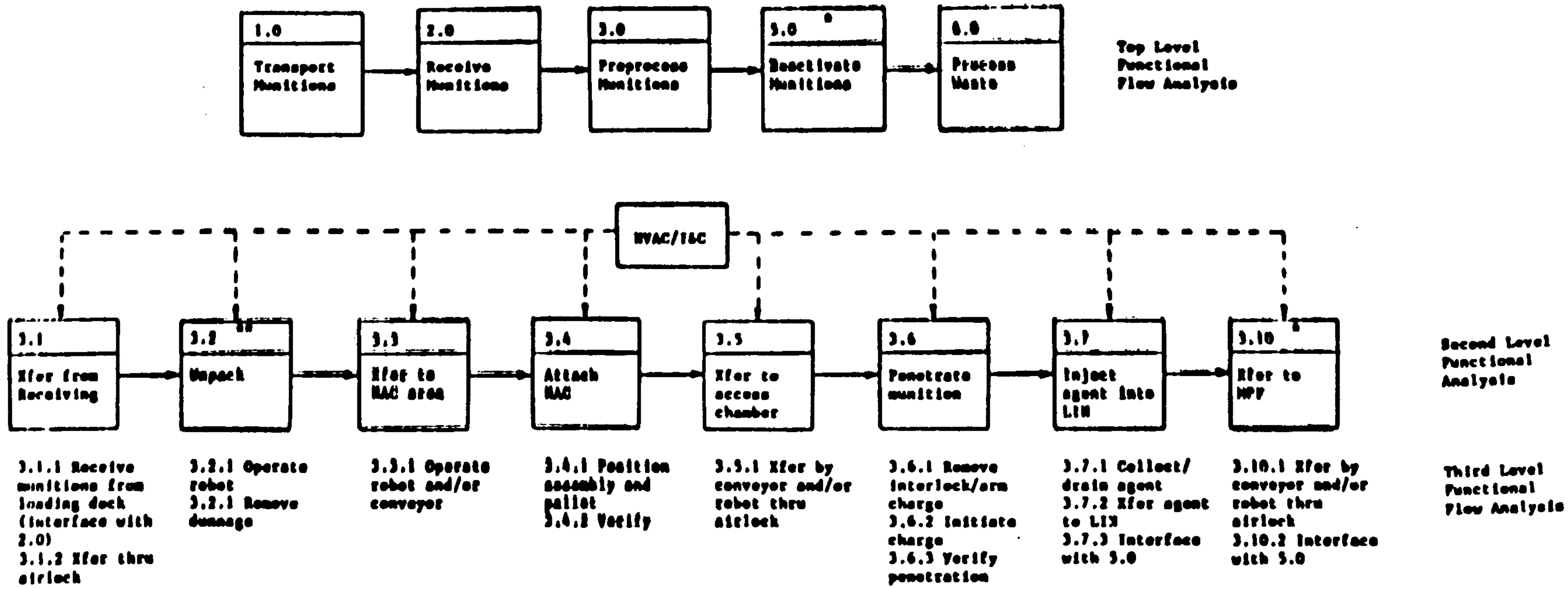
5-2-84

Figure 17



* 4.0 Disassemble
3.8 Chem decon munition (burstered)
3.9 Xport to final site (burstered)

**Unpack task applies if batch processing operational mode is not acceptable.

FUNCTIONAL FLOW DIAGRAM OF HAC PROCESS - NON-BURSTERED MUNITIONS

FIGURE 18

FACILITY NAME:
TASK AREA:
COMPONENT/SUBSYSTEM:
PREPARED BY:____________ **DATE:**__________ **REVIEWED BY:**____________ **DATE:**__________

EVENT DESCRIPTION/REMARKS	HAZARD(a) SEVERITY	MISHAP(b) PROBABILITY	RISK(c) CATEGORY	COMPENSATION AND CONTROL

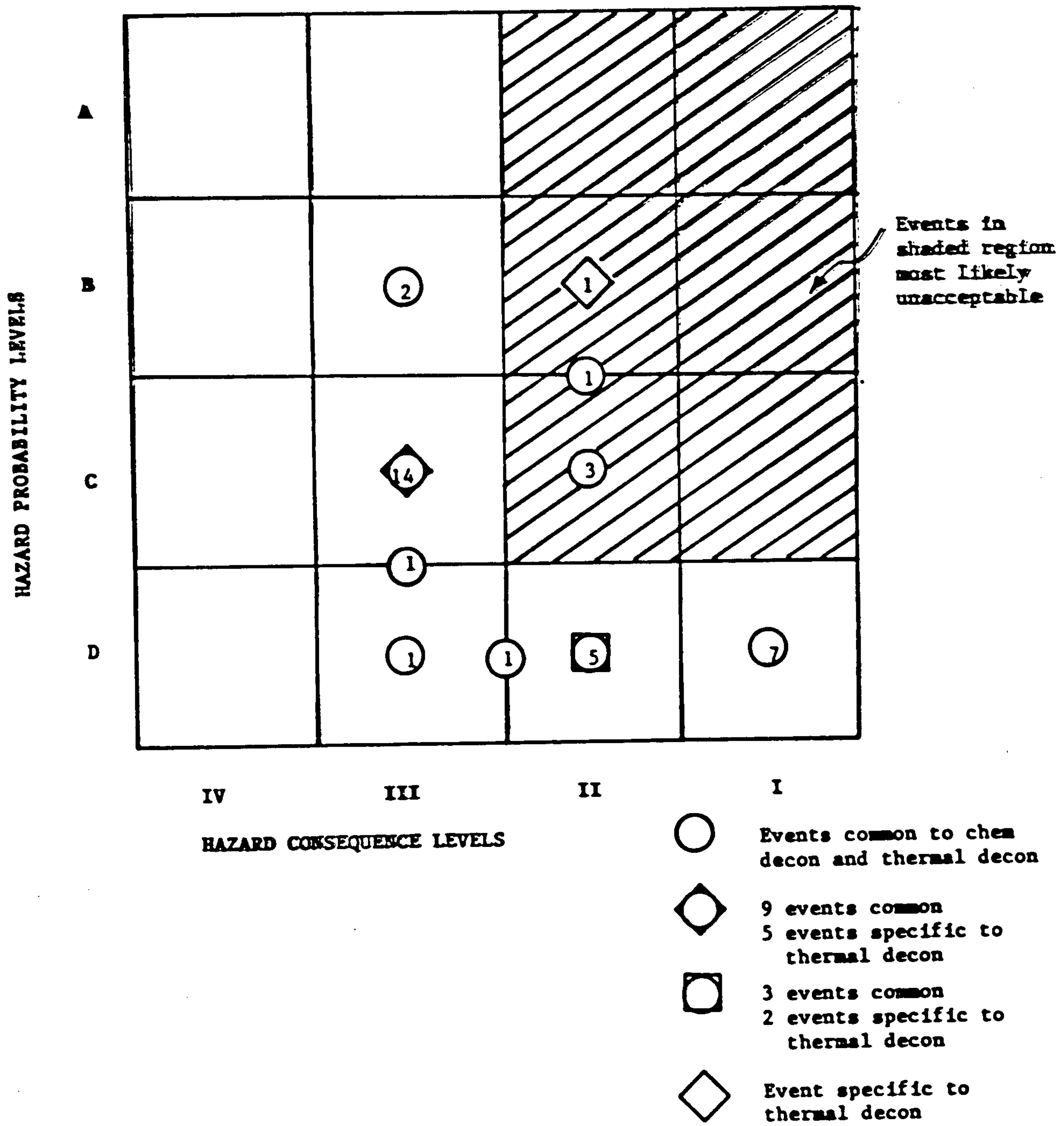
(a) SEVERITY:
I – CATASTROPHIC = MAY CAUSE DEATH/ SYSTEM LOSS
II – CRITICAL – SEVERE INJURY/SYSTEM DAMAGE
III – MARGINAL – MINOR INJURY
IV – NEGLIGIBLE – PROBABLY WOULD NOT AFFECT SAFETY OR HEALTH

(b) PROBABILITY:
A – LIKELY TO OCCUR
B – PROBABLY WILL OCCUR IN TIME
C – MAY OCCUR IN TIME
D – UNLIKELY TO OCCUR

(c) RISK (PROBABILITY * SEVERITY)
1 – AI, BI, AII
2 – CI, BII, AIII
3 – DI, CII, BIII
4 – DII, CIII
5 – DIII

G-433(84)
9-30-83

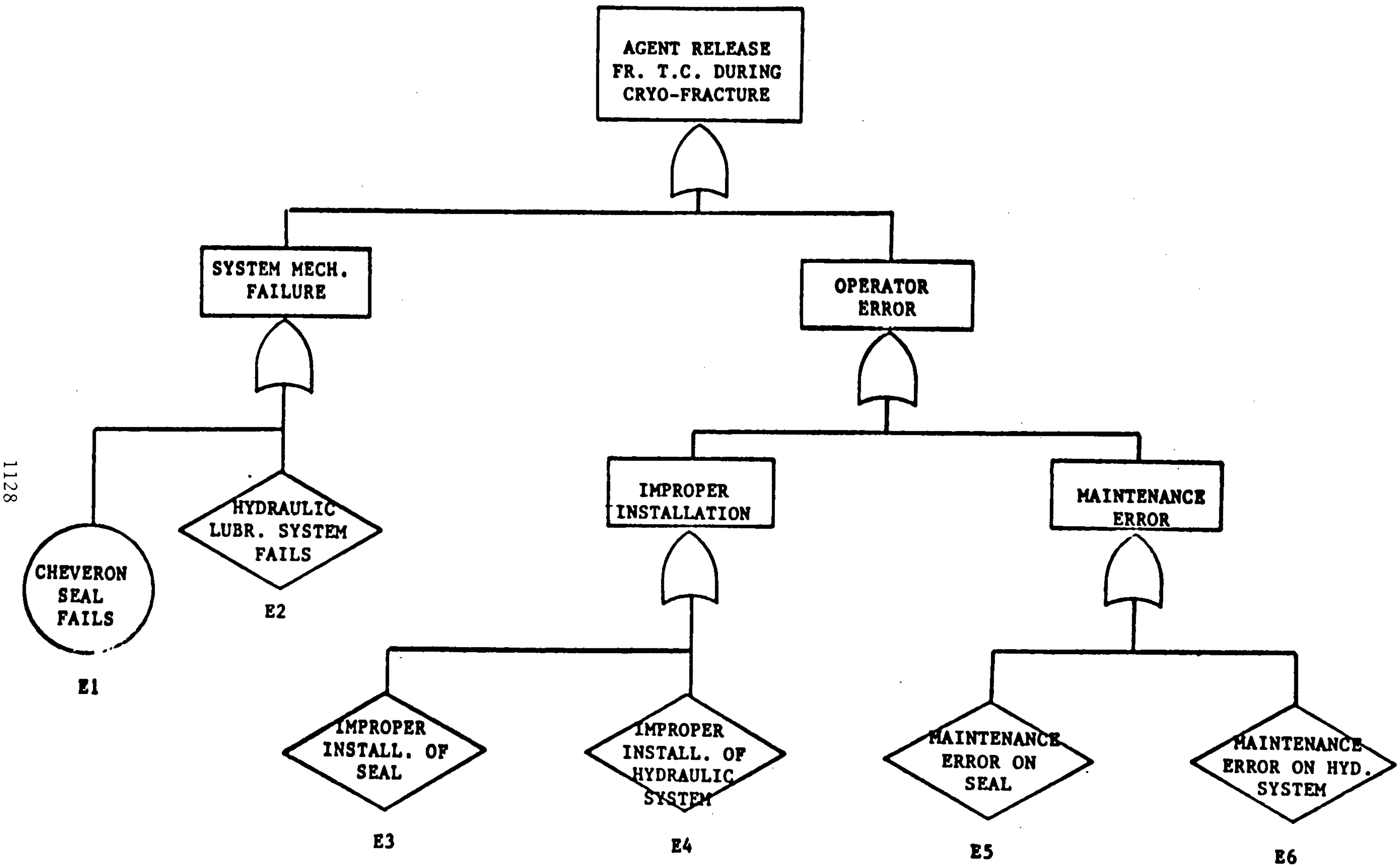
FIGURE 19



PRELIMINARY RISK PROFILE HAC PROCESS

BURSTERED MUNITIONS -- THERMAL DECON

FIGURE 20



CASE I. NO REDUNDANCY AND POOR DETECTION SYSTEM

FIGURE 21

FAULT TREE ANALYSIS OF SEAL FAILURE
(INITIATING EVENT 47 FROM MASTER LOGIC DIAGRAM)

CASE	DESCRIPTION
I	Assumed no redundancy and poor detection system; all single point failures
II	Additional instrumentation system to detect agent release; no redundancy in mechanical/electrical components
III	Multiple redundancies in containment, instrumentation, power source and signal to control room

FIGURE 22

CRYO-FRACTURE OPERATIONS CAUSING AGENT RELEASE

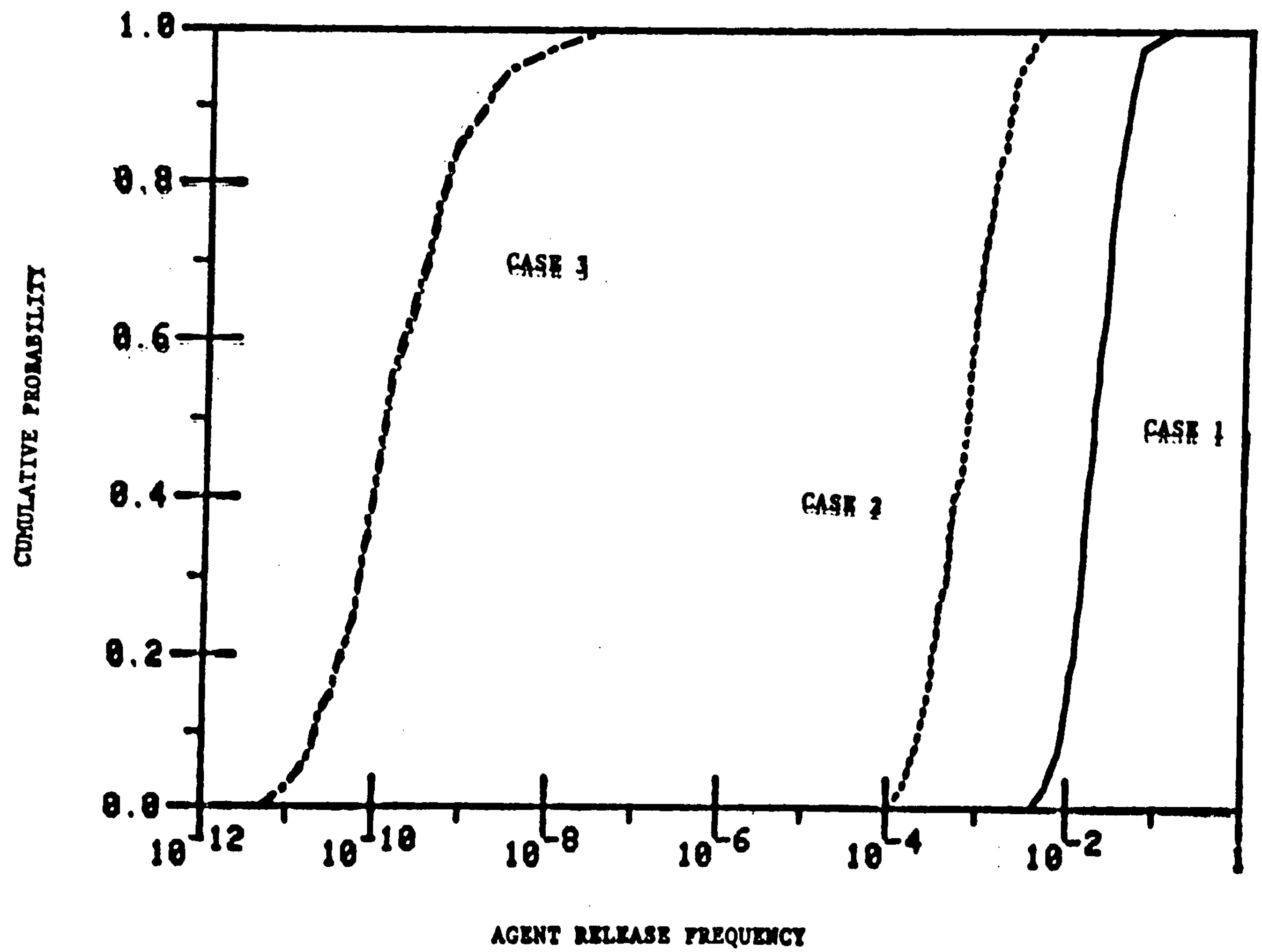


FIGURE 23

CRYO-FRACTURE
PRE-PROTOTYPE FRACTURE OF 155 MM ROUND

BURSTER SIMULANT
AND BURSTER WELL

155 MM PROJECTILE

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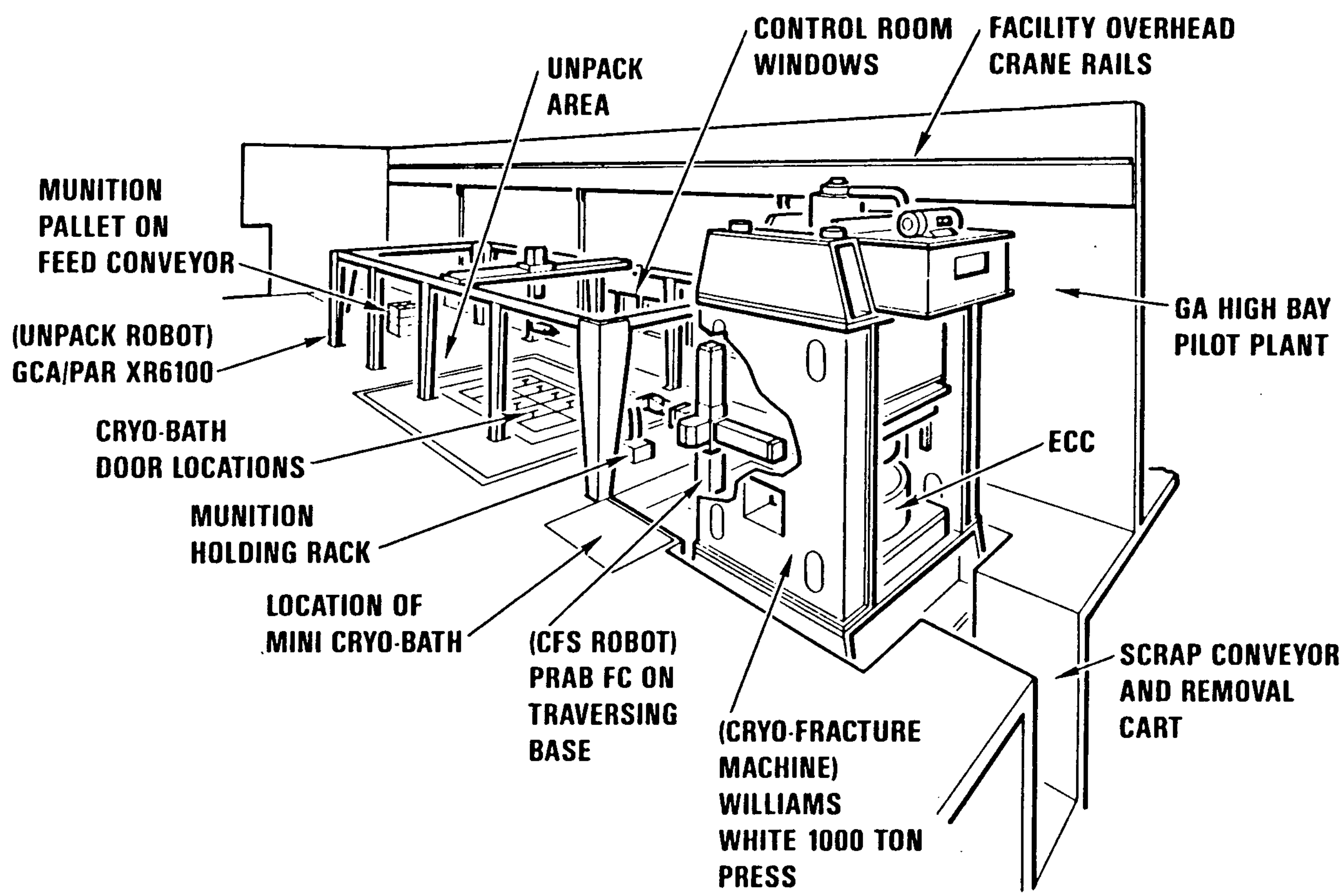
11-1-83

FIGURE 24

ISOMETRIC OF GA TECHNOLOGIES PROTOTYPE FACILITY



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3-21-84

FIGURE 25

TEST RESULTS TO DATE

AGENT CAVITY ACCESS

- LARGEST HOLE SIZE WITH CONICAL SC $\approx$ 1 IN. DIAM.
- CAN CONTROL PENETRATION OF MUNITIONS IN BOXES
- SIMULTANEOUS PENETRATION OF 2 155MM PROJECTILES NOT ACHIEVED WITH 22 GM SC

DISASSEMBLY OF WOOD BOXES POSSIBLE WITH SCs

BURSTER RESPONSE

- AVOIDING DAMAGE TO BURSTER WELL APPEARS FEASIBLE
- SHOCK PRESSURE FROM 22 gm SC DID NOT CAUSE DETONATION
- IMPACT ENERGY FROM 2.5 gm SC DID CAUSE DETONATION

FIGURE 26

GA Technologies

BURSTER RESPONSE CHARACTERISTICS

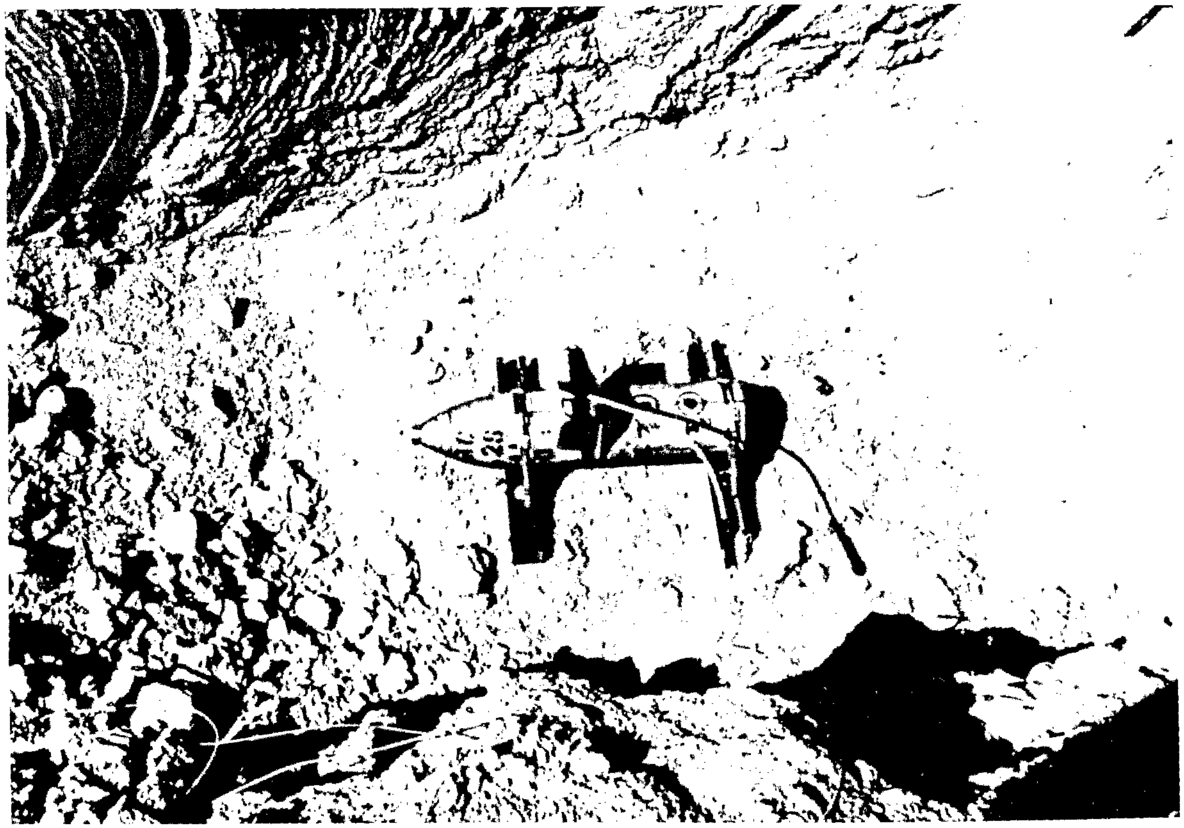
- OBJECTIVES
  - DETERMINE BURSTER DETONATION THRESHOLD
  - EVALUATE BLAST EFFECT OF DETONATED MUNITION WITH DRAINED CAVITY
- ANALYTICAL RESULTS
  - JET IMPACT SHOULD NOT DETONATE EXPLOSIVE
  - DRAINED CHEMICAL PROJECTILE BODIES SHOULD ACT AS BLAST CONFINEMENT
- BENCH TEST RESULTS
  - BURSTERS DO NOT DETONATE FROM SHOCK INITIATION
  - TESTS CONFIRM ABILITY OF SHELL TO REDUCE BLAST EFFECT OF BURSTER
  - THERMAL INITIATION CONTROLLED BY SHAPED CHARGE SIZE AND LOCATION

G-718(1)
6-6-84

Figure 27

GA Technologies

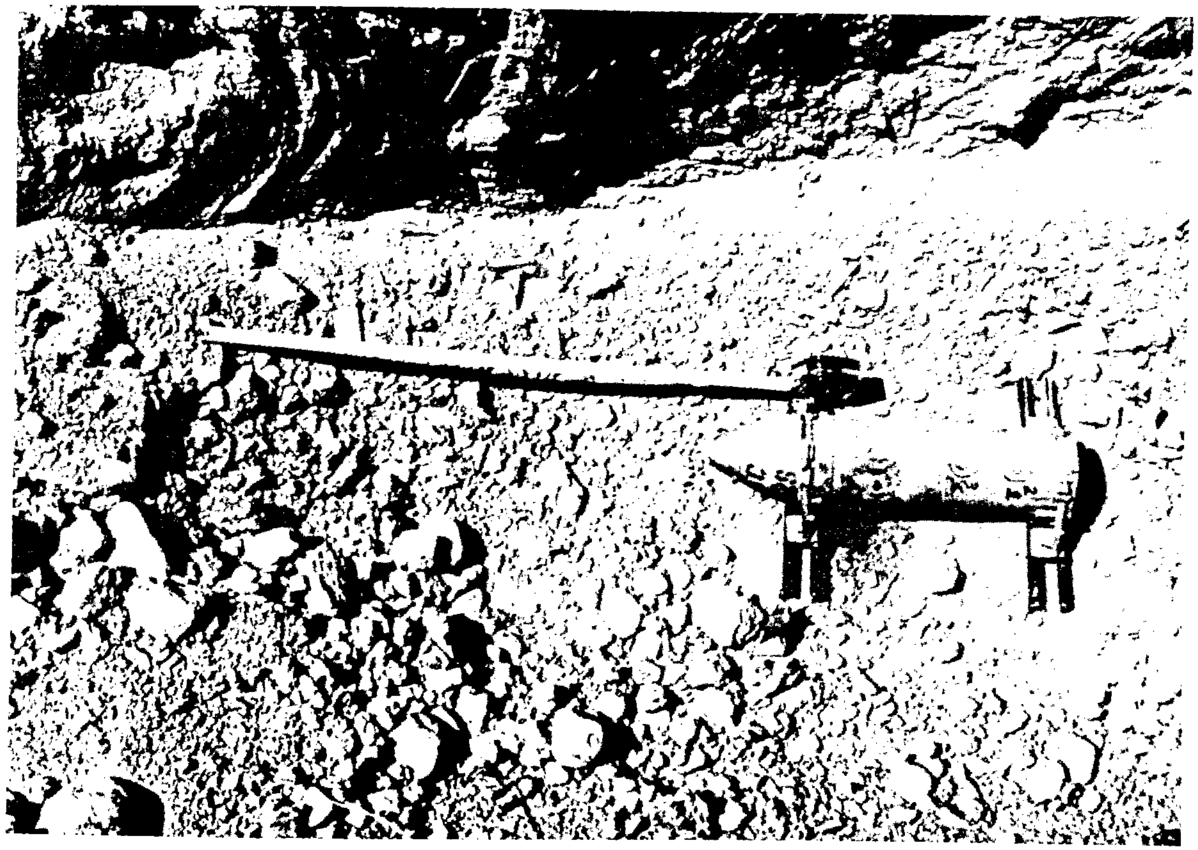
4.2–IN. MORTAR, BURSTERED WITH 20.5 GM SC POSITIONED FOR FIRING, AIMED TO MISS BURSTER



G 686(9)
5 21 84

FIGURE 28

RESULTS FROM 20.5 GM SC, NO DETONATION, NOSE PIECE OF FUZE BROKEN, ~2 FT AWAY

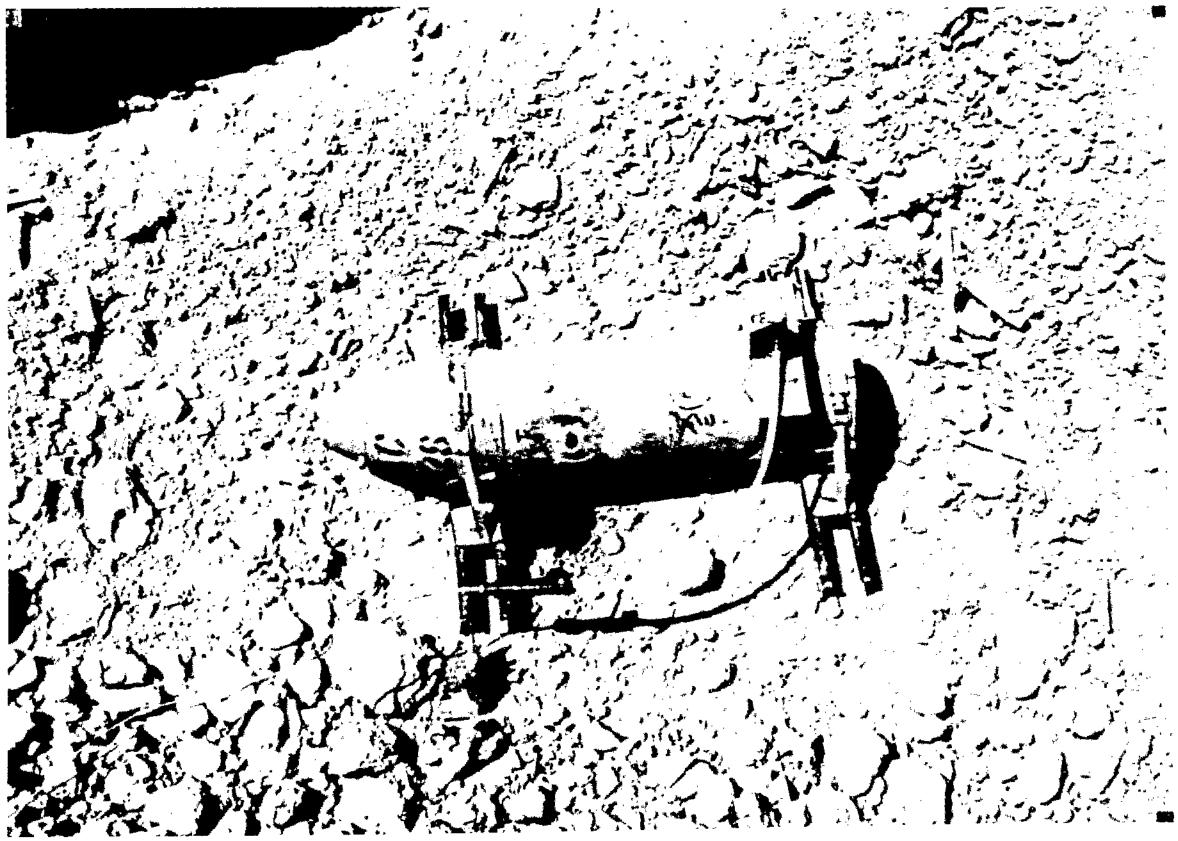


G 686-8
5 21 84

FIGURE 29

GA Technologies

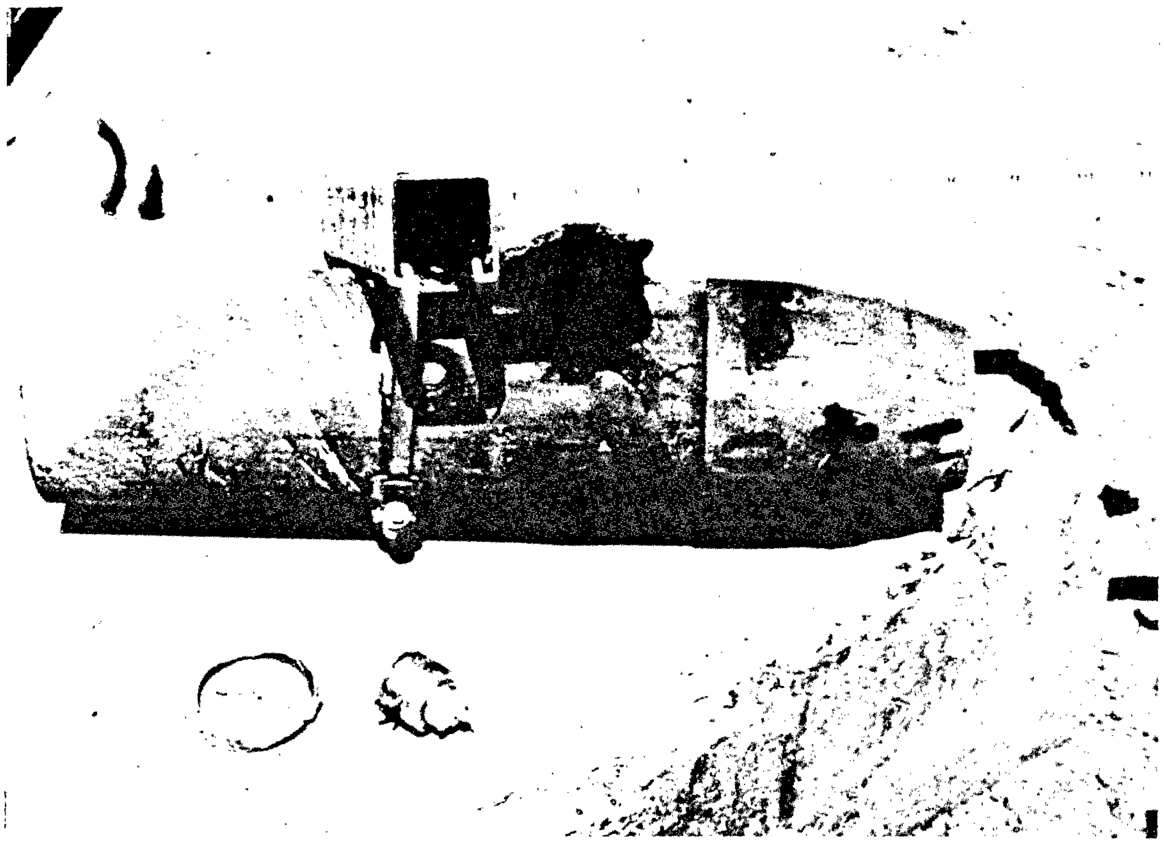
4.2–IN. MORTAR, BURSTERED, SECOND SC 2.5 GM POSITIONED FOR FIRING DIRECTLY AT BURSTER



G 686(10
5-21 84

FIGURE 30

RESULTS OF 2.5 GM SC HITTING BURSTER.
BURSTER DESTROYED.
CASING SPLIT OPEN BUT NO FRAGMENTATION.
FRAGMENTS BELONG TO FUZE.



5 686 11
6 21 84

FIGURE 31

RESULTS OF HITTING 105 MM, BURSTERED. FIRST SHOT 20.5 GM SC AIMED TO MISS BURSTER. SECOND SHOT 2.5 GM SC AIMED DIRECTLY AT BURSTER. BURSTER WAS DESTROYED. CASING NOT DAMAGED.

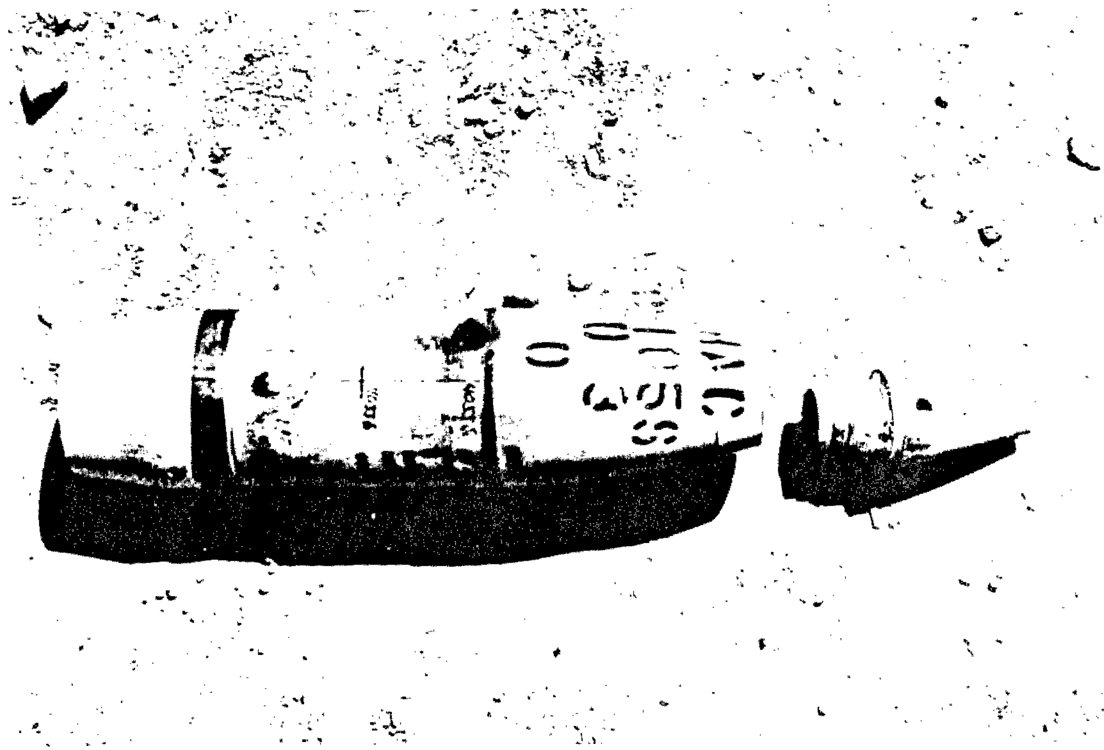


FIGURE 32

Figure 33

Figure 34

COMPLEXITIES OF LEAD AZIDE

Prepared By:
Mr. William Shaneyfelt
Safety Officer,
Savanna Army Depot Activity
Savanna, Illinois

Presented at the
DDESB Explosives Safety Seminar
Houston, Texas
29 August 1984

1. GENERAL.

a. Lead azide, $Pb(N_3)_2$, is an explosive salt of hydrazoic acid, HN_3, having a molecular weight of 291.258. It is very sensitive to impact, friction, heat, and electrical discharge. Its soluability is less than 1% in cold water and nearly zero in ammonium hydroxide solution, ether, acetone, or ethanol, but it is quite soluable in heated, strongly acid or strongly alkaline solutions. When dry, it does not corrode most metals, however, in the presence of moisture, gold, silver, copper, mercury, tin, and zinc, all form extremely sensitive and dangerous azides.

b. Pure lead azide occurs as colorless needle-like crystals. Breaking these crystals is believed to initiate detonation. Military-use lead azide is white to tan with crystals less than 0.1mm long to minimize sensitivity. It is approximately 92% pure, having about 4% lead hydroxide (a manufacturing by-product), 3% dextrin (a binder), and 1% trace impurities.

2. ACCUMULATION. Vietnam-era jungle warfare fostered the development of munitions using relatively enormous quantities of lead azide. Their sensitivity to detonation caused a reluctance among many users to deploy them, resulting in a stockpile of both munitions and bulk lead azide. The winding down of hostilities left a vast supply and an extremely small demand. Mounting environmental regulations limited most open-air detonations to emergency destruction of immediately hazardous munitions. All munitions were eventually destroyed, leaving the stockpile of bulk lead azide in deteriorating 55-gallon drums.

3. STORAGE. Long-term storage of lead azide presents some problems. Primarily, its extreme sensitivity when dry necessitates under water storage. Next, if the water freezes, spontaneous detonation occurs, presumably due to ice crystal formation breaking lead azide crystals. Addition of ethanol to the water is therefore necessary to make a non-freezing mixture. Periodic surveillance is then required both visually to assure adequate liquid level and testing to determine if ethanol evaporation has reduced antifreeze properties. Finally, the steel 55-gallon packing and storage drum has a limited life due to rust-through, which eventually results in leakage of the ethanol-water mix.

4. DISPOSAL RESEARCH. Early attempts to sell the stockpiled lead azide were fruitless, so the search for the best nonpolluting disposal method began. Lead azide can be converted to less sensitive or nonexplosive substances in many ways. There are also problems with each method. Some of the better known disposal methods are:

a. Lead azide can be dissolved in 10% sodium hydroxide forming toxic lead hydroxide and the extremely insensitive but highly toxic sodium azide. This is very time consuming and produces large quantities of hazardous chemically active waste residues which can later react to form sensitive explosive compounds.

b. Dissolving lead azide in a solution of ammonium acetate and potassium or sodium bichromate forms toxic lead chromate. A sensitive explosive sludge may also form. Again, hazardous waste residues are a problem.

c. Lead azide dissolved in a solution of sodium nitrite is destroyed by adding 36% nitric acid or glacial acetic acid while stirring. This is an extremely bulky method resulting in approximately 65 gallons of hazardous waste per pound of lead azide destroyed. Rapid heat production by this complete reaction can be hazardous, so addition of acid must be slow. The added severe hazard of hydrazoic acid also exists. Hydrazoic acid is both a highly sensitive explosive and extremely toxic. Since its boiling point is about 37° C (99° F), hydrazoic acid is also very volatile, creating additional serious containment problems.

d. Lead azide dissolved in ammonium acetate solution receives sodium nitrite, is stirred, and then receives glacial acetic acid while stirring. This also forms large quantities of hazardous wastes. It can only be done in small quantities, is slow, and risks forming hydrazoic acid.

e. Often preferred, a solution of 20-25% ceric ammonium nitrate decomposes lead azide, producing a gas in the reaction, a good indicator of reaction completion when the bubbling stops. Only small quantities may be reacted at one time due to possibility of a violent reaction. Chemicals for the process are expensive.

NOTE: The first five methods were devised for destruction of small quantities of lead azide.

f. Heating lead azide to 240-250° C (464-482° F) results in escape of nitrogen and deposit of metallic lead residue. Since the reaction is exothermic (releases heat), it is difficult to avoid reaching temperatures of 340-350° C (644-662° F) at which explosion occurs. This method was never even documented as an alternative, presumably due to its obvious hazards.

g. In the late 1960s, electrolytic decomposition of lead azide dissolved in sodium hydroxide was developed. This appeared to be a very attractive alternative due to its low chemical cost, nonpolluting nature, and production of marketable chemical lead.

5. PRODUCTION.

a. The electrolytic process was experimentally pursued and scaled up to approach production capacity. Many hazards of the process (electrical, fire, explosion, chemical, toxicity, heat, handling, etc.) were recognized and countermeasures established during the initial process development. An in-depth 163-page hazards analysis was produced, including 64 pages of risk-tree analysis, with a major effort necessarily devoted to fire and explosion hazards.

b. An industrial hygiene study by USAEHA recognized hydrazoic acid as a matter of grave concern in the process. In an acid solution, azide

ions combine with acidic hydrogen ions to form hydrazoic acid, a sensitive explosive and also being a potently toxic vapor, immediately permiates its surroundings with its hazards when evolved. To abate the hydrazoic acid problem, airline respirators were put into service, except for certain intermittent operations which required the mobility afforded by a cartridge respirator. An exhaust hood with shrouds was installed to contain all possible air contaminants. Physiological monitoring of workers provided a positive indicator of any exposure. Despite the protective measures, physiological monitoring indicated significant over exposure to azides. Sorbent filter air monitoring in the work bay tested positive for azides beyond acceptable limits. To specifically isolate hydrazoic acid as a problem, an industrial hygiene survey of the air was taken again using a sorbent filter to capture the gaseous hydrazoic acid vapor, however, this time, a prefilter was used to capture particulates. No hydrazoic acid was found, proving that it was sodium azide in particulate form that had been transferred due to inadequate housekeeping and poor personal hygiene to insides of masks, hands, faces, and personal articles where it was absorbed and ingested by workers. A vigorous program of housekeeping, personal hygiene, and mask cleaning eliminated the problem. This is just one example of many serious problems which can occur when details are overlooked. Emphasis placed on hydrazoic acid overshadowed other problems. In reality, since hydrazoic acid can only be produced in an acid solution, the strongly alkaline electrolytic solution could not have produced it. This resulted in time and effort wasted attempting to "kill an already dead rat" while the real problem ran unchecked.

c. Sludge formation was noted early in the development of the process, but received little attention. Not until early in the production phase when electrical arcing occurred as sludge buildup on the tank bottom reached the plating electrodes did it become a concern. Consisting primarily of lead hydroxide, it was then generally considered a nuisance which must be periodically removed. Gradually, the sludge, being stored in 55-gallon drums, accumulated. Attempts to dispose of the sludge as normal hazardous waste met with problems. It could not be certified free of explosives without being incinerated. Incineration was out of the question because of pollution, cost, and other technical considerations. Without certification, it could not be accepted by hazardous waste sites. To complicate matters, the caustic nature of the sludge accelerated aging of the storage drums. Occasional leakers fostered visions of famous photographs showing rusted-out drums leaking toxic wastes into our waterways. Such fears prompted moving the sludge from open storage to inside storage. Later, it was all repacked into new steel 55-gallon drums with polyethylene liners to await final disposal. Again, this is an example of a minor nuisance which became a major problem.

d. One other problem was never considered and in fact did not surface until a few months ago. Over the years, pieces of iron pipe, wood, gloves, nails, and various other trash accumulated under the electrolysis building ramps. Among them were a few items with brass or copper parts lying partly buried in the damp, sandy soil over the years. This apparently resulted in a reaction between the brass and the sodium azide which had been hosed out of work bays by the daily washdowns during production. Extremely sensitive

copper azide was thus produced. A loud, though not extremely dangerous, explosion occurred when encountered by personnel, prompting an intense investigation revealing more explosive items (chromed brassbuckle, one-inch hose with brass coupling, and a three-inch piece of copper cable). The area was cleaned up, debris flashed, and the building permanently marked not to be used for high explosives operations. The important point is, any place that has ever been used for processing initiating explosives should be investigated to assure that a similar problem does not exist. Such a precaution may prevent some future investigating team from coming to a wrong conclusion after they sift through the remains around some big smoking hole.

6. CONCLUSION. A plethora of problems were overcome, such as implementation of respiratory program requirements, OSHA lead standard requirements, personnel monitoring requirements, hazards of hydrogen gas generated, grounding and bonding requirements, work area humidity tolerances, conductive and nonstatic work clothes, and many others covered in hazard analyses, SOPs, other studies, and actual operation countermeasures. The future value of the lead azide electrolysis project lies in its example which should reawaken us to problems which can so easily occur. It should inspire us to avoid oversights when implementing new technology, but not needlessly thwarting progress when problems can be solved.

7. UPDATE.

a. The electrolysis project was halted after approximately half the stockpile was destroyed. The remaining drums in storage began leaking more frequently due to corrosion and were finally repacked, giving them another 10 to 15 years before they will need repacking again. A commercial concern is currently interested in procuring the remaining stockpile of bulk lead azide from the Army.

b. The sludge remains stored in polyethylene lined drums. Processes are underway to contract for its disposal.

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YIELD-LINE ANALYSIS OF RECTANGULAR SLABS WITH DOORS

by

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August 1984

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PURPOSE

This paper presents several possible yield-line failure mechanisms and the corresponding equations for the ultimate flexural resistance of a slab with a door when subjected to a uniform pressure. The equations are limited to rectangular slabs with openings and are the beginning of an effort at the Naval Civil Engineering Laboratory to develop a comprehensive design procedure for rectangular slabs subjected to blast loads.

BACKGROUND

Blast design within the Department of Defense is currently performed using procedures outlined in the Tri-Services manual 'Structures to Resist the Effects of Accidental Explosions' (NAVFAC P-397). The ultimate flexural resistance of reinforced concrete slabs is determined using the yield-line analysis method. The P-397 manual presents charts and equations for determining the ultimate flexural resistance, r_u, of rectangular slabs restrained by a variety of support conditions. The yield-line principles used in deriving these equations are presented so derivations of equations for more complex applications can be performed by the user.

A very common structural element encountered by the blast designer is a wall with a door. No guidance is presented in P-397 on how to analyze such a slab. The door opening interrupts the continuity of the steel reinforcement and can significantly weaken the slab. Further, dynamic response of the door over the opening transmits a line load along the perimeter of the opening. This line load further reduces the load capacity of the slab.

Common practice among design engineers at present is to reinforce the door opening with pillasters and a lintel beam. This in effect subdivides the slab into sections that are much easier to analyze. The pillasters and lintel beam are normally designed to resist the door load and provide nondeflecting support.

These simplifications can at times unnecessarily increase construction costs and may result in over-conservative designs. A yield-line analysis that considers the slab to act as a unit can aid in developing a design that utilizes the construction materials much more efficiently. Further, the analysis procedure provides a basis for judging the need for pillasters.

Several possible failure mechanisms for slabs with openings have been identified and the appropriate equations derived to calculate r_u.

TECHNICAL APPROACH

The design equations were derived using the equilibrium method of the yield-line analysis technique. An equation is derived to calculate r_u for each sector of the assumed failure mechanism. This equation is of the form

$$\Sigma M_N + \Sigma M_P = r_u A c_1 + q c_2 + V c_3 \qquad (1)$$

where ΣM_N = sum of the ultimate unit resisting moments acting along the yield-lines of negative moments (supports)

ΣM_P = sum of the ultimate unit resisting moments acting along the yield-lines of positive moment (interior failure lines)

r_u = ultimate unit resistance of the sector

q = nodal force or concentrated point load applied to the sector

V = line load applied to the sector

A = area of the sector

c_1 = distance from the centroid of the uniform load to the line of rotation of the sector

c_2 = distance from the point load to the line of rotation of the sector

c_3 = distance from the centroid of the line load to the line of rotation of the sector

The ultimate unit moment capacities are determined as outlined in NAVFAC P-397. The variables in these equations define the exact locations of the yield-lines. The r_u of the entire slab is determined when a specific location of yield-lines is identified that yields the same r_u for each sector. Figure 1 illustrates a typical yield line failure mechanism for a rectangular slab.

Twisting moments and shear forces that occur along the yield-lines introduce imbalances in the equalibrium equations for each sector. The imbalance should be taken into account by using nodal forces at the intersections of yield-lines with each other and with free, unsupported edges, e.g., perimeter of door opening. In many instances the nodal forces in adjacent sectors cancel each other out. In the development of the design equations presented here, nodal forces are only required when a positive yield-line intersects a free edge at an angle other than 90 degrees. The concept of nodal forces is not presented Reference 1. The equation for the nodal force that acts at the intersection of a yield-line with a free edge is

$$Q = M_{py} \cot \alpha \tag{2}$$

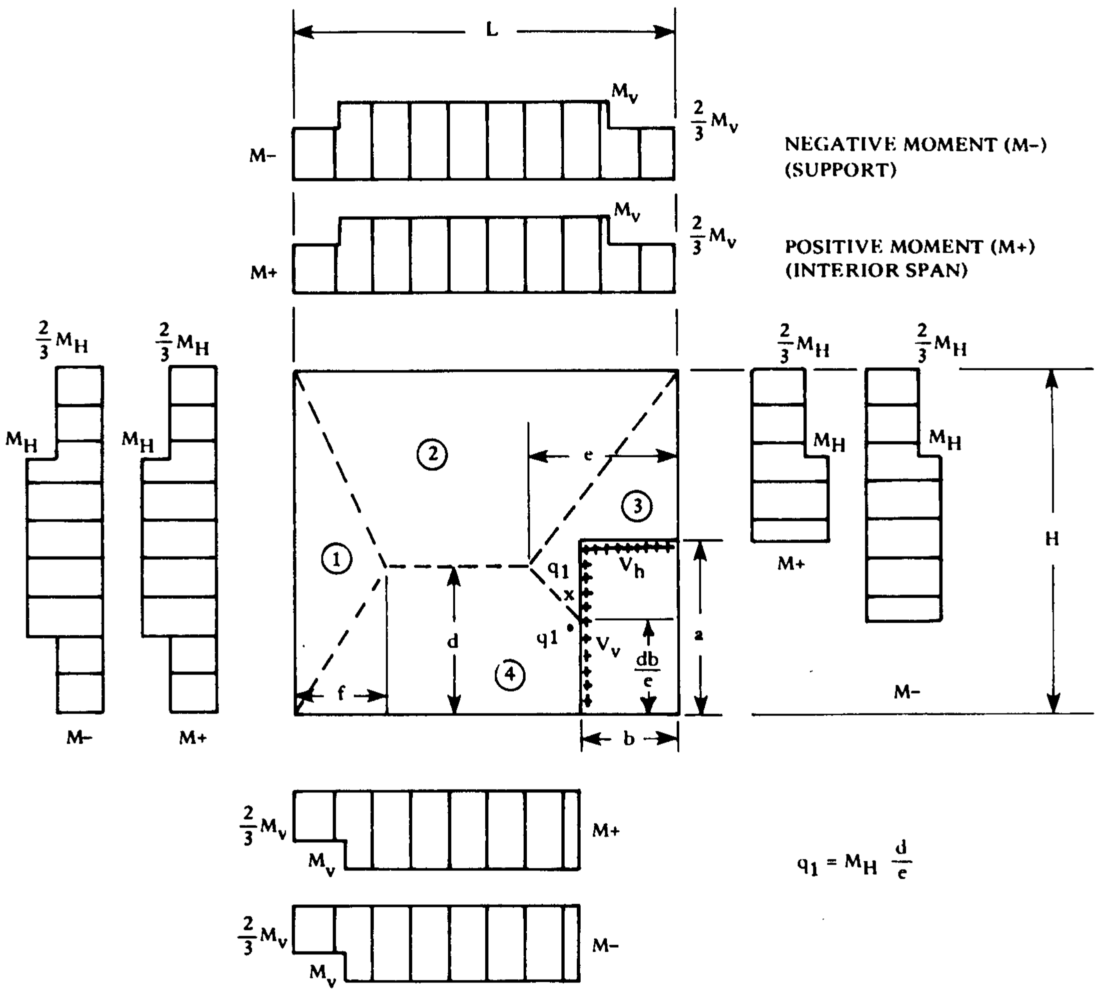
where α is the angle of intersection of the yield-line with the free edge (α < 90 degrees), and M_{py} is the ultimate unit moment capacity of the slab in a direction normal to the free edge. The nodal force is treated as a point load that acts upward in the obtuse angle and down ward in the acute angle (Figure 2).

The horizontal and vertical line loads around the door opening are determined from a yield line analysis of the door. The total external line load applied to the door frame is obtained as outlined in NAVFAC P-397 by calculating the shear force along the edge of the door and applying a 2/3 reduction factor in the corners. The average line load along the edge is computed and assumed to act as a uniform load as shown in Figure 3.

The equations are presented in a general form which allows for different moment capacities in the x (horizontal) and y (vertical) directions. Positive and negative moment capacities of the slab are constrained to be the same in both diractions, i.e., $M_{Nx} = M_{Px}$ and $M_{Ny} = M_{Py}$. The line loading along the edge of an opening is assumed to be uniform along the length of each edge, but the horizontal line load may differ from the vertical line load.

A two-thirds reduction in moment capacity on all yield-lines extending into corners is assumed as per NAVFAC P-397. This reduction extends along the yield-line from the corner midway to the intersection of a second yield-line or a free edge.

To illustrate how the equations were obtained, the derivation of the design equations for the yield-line pattern #1 (Figure 4) is shown below.



Equation for Sector 1

$$144\ r_1\left[\frac{1}{2}\ (Hf)\ \frac{f}{3}\right] = 2\left(\frac{2}{3}\right)M_H\ \left(\frac{H-d}{2}\right) + 2M_H\left(\frac{H-d}{2}\right) + 2\left(\frac{2}{3}\right)M_H\ \left(\frac{d}{2}\right)$$

$$+\ 2M_H\left(\frac{d}{2}\right)$$

$$r_1 = \frac{5M_H}{72f^2}$$

Equation for Sector 2

$$144r_2\left[\frac{1}{2}\ f(H-d)\ \left(\frac{H-d}{3}\right) + (L-f-e)(H-d)\ \left(\frac{H-d}{2}\right)\right] + \frac{1}{2}\ e(H-d)\ \left(\frac{H-d}{3}\right) =$$

$$2\left(\frac{2}{3}\ M_v\right)\frac{f}{2} + 2M_v\ \left(\frac{f}{2}\right) + 2M_v(L-e-f) + 2\left(\frac{2}{3}\ M_v\right)\frac{e}{2} + 2M_v\ \left(\frac{e}{2}\right)$$

$$r_2 = \frac{M_v(6L-f-e)}{72(H-d)^2(3L-2f-2e)}$$

Equation for Sector 3 $\qquad q_1 = M_H(d/e)$

$$144r_3\left[\frac{1}{2}\ eH\left(\frac{e}{3}\right) - \frac{1}{2}\left(\frac{db}{e}\right) b\left(\frac{b}{3}\right) - \left(a - \frac{db}{e}\right) b\left(\frac{b}{2}\right)\right] + V_v\left(a - \frac{db}{e}\right) b$$

$$+\ V_H b\left(\frac{b}{2}\right) = 2\left(\frac{2}{3}M_H\right)\left(\frac{H-d}{2}\right) + M_H\left(\frac{H-d}{2}\right) + M_H\left(d - \frac{db}{e}\right)$$

$$+\ M_H\left[H-a-\left(\frac{H-d}{2}\right)\right] - q_1 b$$

$$r_3 = \frac{M_H\left(10H + 2d - 12\,\frac{db}{e} - 6a\right) - 3V_h b^2 + 6V_v\left(ab - \frac{db^2}{e}\right)}{144\left(He^2 + 2\,\frac{db^3}{e} - 3b^2 a\right)}$$

Equation for Sector 4

$$144r_r\left[\frac{1}{2}\ f\ d\left(\frac{d}{3}\right) + (L-e-f)d\left(\frac{d}{2}\right) + \frac{1}{2}\ e\ d\left(\frac{d}{2}\right) - \frac{1}{2}\ b\left(\frac{db}{e}\right)\left(\frac{db}{3e}\right)\right]$$

$$+ V_v\left(\frac{db}{e}\right)\left(\frac{db}{ze}\right) = 2\left(\frac{2}{3}\ M_v\right)\frac{f}{2} + 2M_v\left(\frac{f}{2}\right) + 2M_v(L-b-f) + q_1\left(\frac{db}{e}\right)$$

$$r_4 = \frac{2M_v(6L-f-6b) + 6M_H\left(\frac{bd^2}{e^2}\right) - 3V_v\left(\frac{db}{e}\right)^2}{144d^2\left(3L - 2f - 2e - \frac{b^3}{e^2}\right)}$$

RESULTS

The selected failure mechanisms and the corresponding design equations for computing r_u are shown in Figures 4 through 15. The critical failure mechanism for a given slab is the one that yields the lowest value for r_u. The recommended method of solution is to vary combinations of x, y, and z until r_u of each sector is identical. This often requires several trial solutions. Further, several mechanisms must be tried to determine which is the most critical. If a set of equations fail to converge, then that mechanism is not valid for that particular case.

FUTURE WORK

Additional failure mechanisms for rectangular slabs with openings will be documented and included with this collection as they are identi fied. Design equations for the ultimate shears associated with these failure mechanisms will be derived. To enable the design engineer to predict dynamic response of the slab to blast loads, a method will be developed to calculate the stiffness and natural period of the slab.

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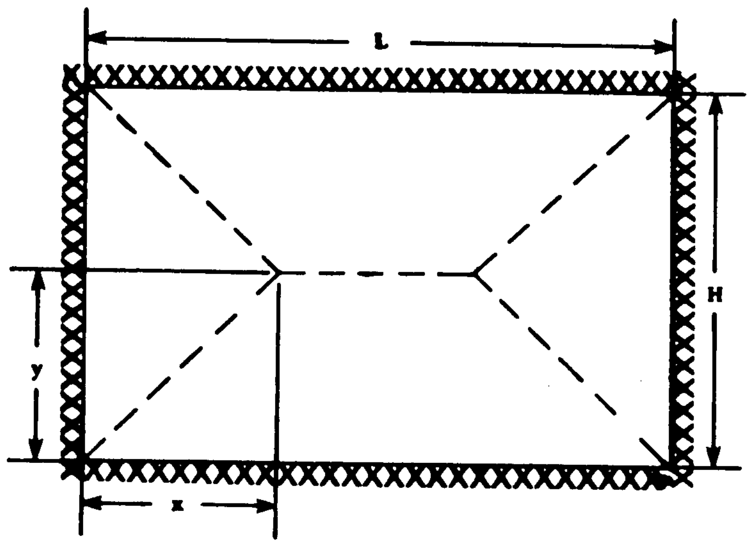


Figure 1a. Typical yield lines for a rectangular slab.

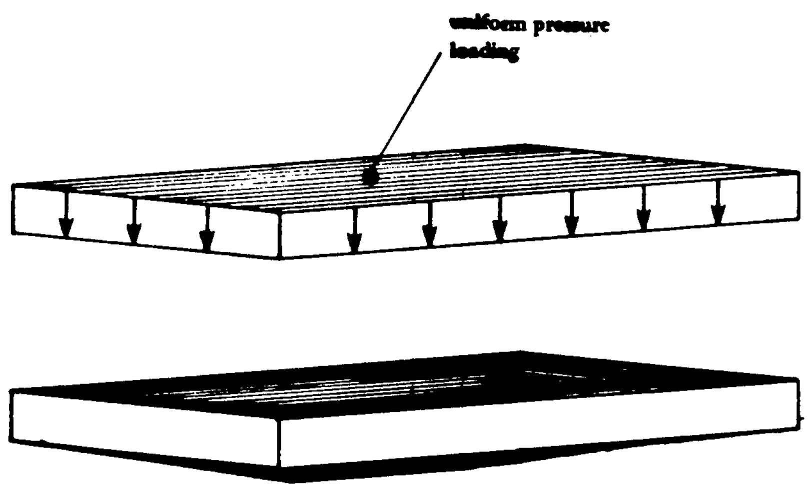


Figure 1b. Deflection of a uniformly loaded rectangular slab.

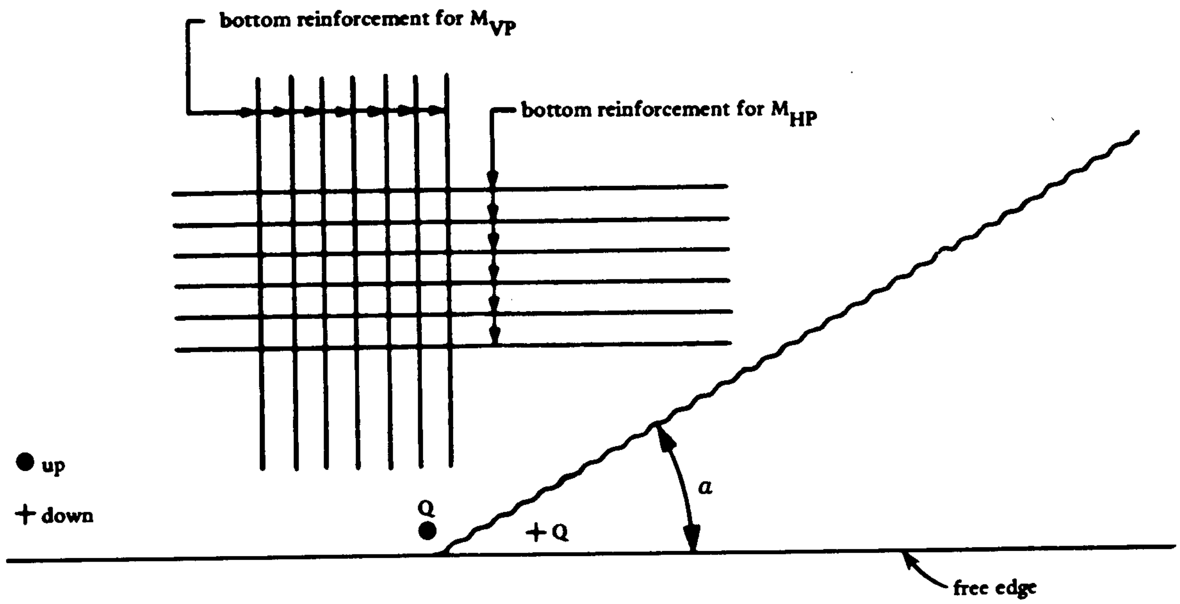


Figure 2. Nodal forces on slab with free edge.

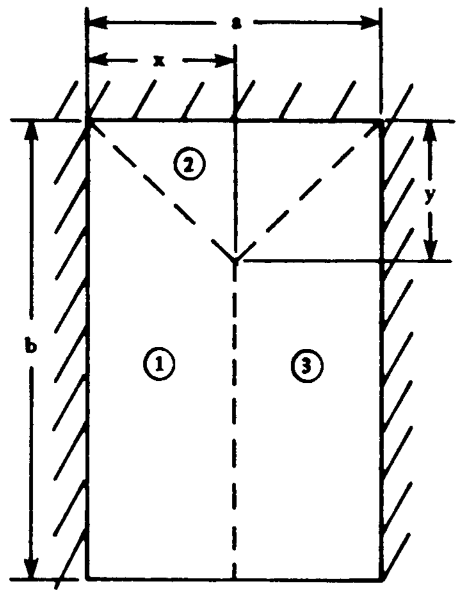
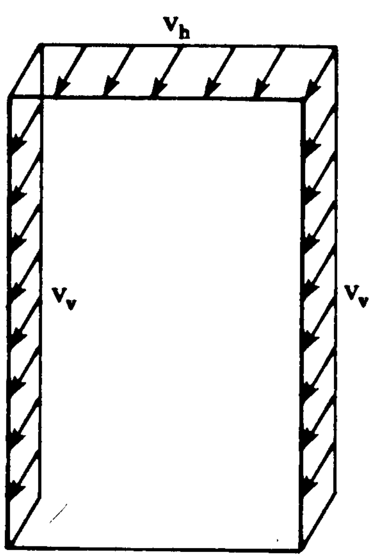


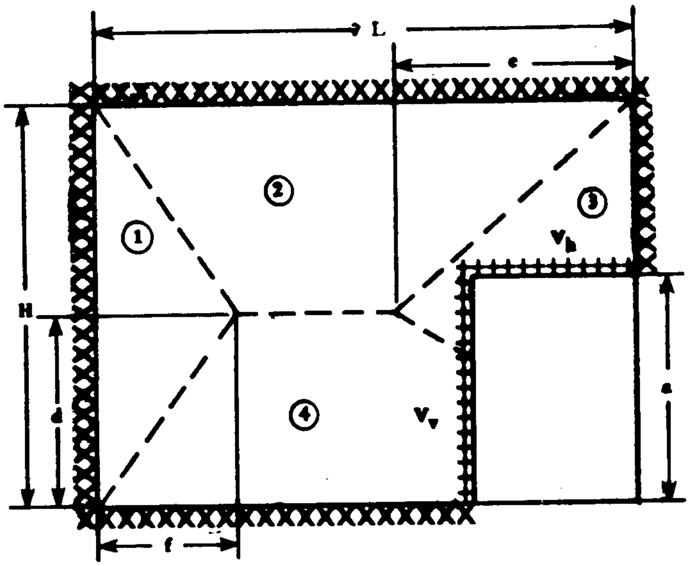
Figure 3a. Typical yeild line pattern of a steel door simply supported along three sides and free along the fourth.



$$V_v = \frac{3r_u y}{5}\left[1 - \left(\frac{2}{9}\right)\left(\frac{y}{b}\right)\right]$$

$$V_h = \frac{5r_u a\left(2 - \frac{y}{b}\right)}{4\left(6 - \frac{y}{b}\right)}$$

Figure 3b. Line loads acting along supports of door.



$$r_1 = \frac{5M_H}{72f^2}$$

$$r_2 = \frac{M_v(6L-f-e)}{72(H-d)^2(3L-2f-2e)}$$

$$r_3 = \frac{M_H\left[10H + 2d - 12\left(\frac{db}{e}\right) - 6a\right] - 3V_h b^2 + 6V_v\left(ab - \frac{db^2}{e}\right)}{144\left(e^2H + \frac{2db^3}{e} - 3b^2a\right)}$$

$$r_4 = \frac{2M_v(6L-f-6b) - 3V_v\left(\frac{db}{e}\right)^2 + 6M_H\left(\frac{bd^2}{e^2}\right)}{144d^2\left(3L - 2f - 2e - \frac{b^3}{e^2}\right)}$$

where: r = resistance of segment, psi

M_H = ultimate moment capacity in horizontal direction, in.-lb/in.

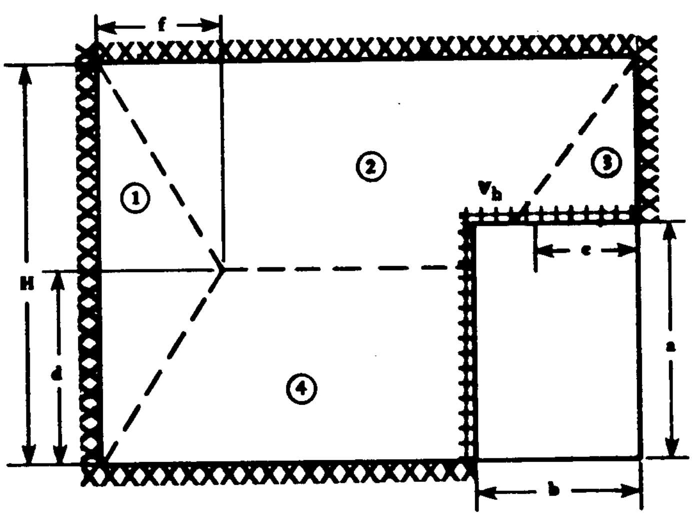
M_v = ultimate moment capacity in vertical direction, in.-lb/in.

V_v = average shear in horizontal span of door acting as line load along vertical edges of opening, lb/ft

V_h = average shear in vertical span of door acting as line load along horizontal edges of opening, lb/ft

Note: Dimensions in feet.

Figure 4. Yield-Line pattern #1.



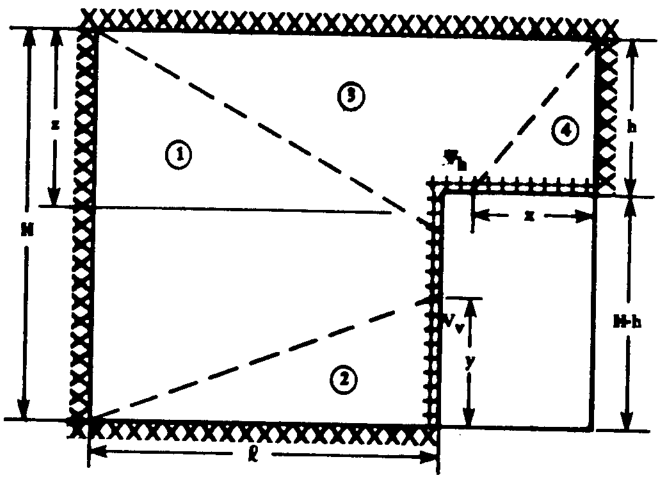
$$r_1 = \frac{5M_H}{72f^2}$$

$$r_2 = \frac{2M_v(6L-f-3b+4e) - 3V_h(b-e)(H-a) - 3V_v(a-d)(2H-d-a)}{72[2f(H-d)^2 + 6(H-d)^2(L-f-b) + 3(b-e)(H-a)^2 + 2(H-a)^2e}$$

$$r_3 = \frac{10M_H(H-a) - 3V_h e^2 - 6M_v\left(\frac{e^2}{H-a}\right)}{144(H-a)e^2}$$

$$r_4 = \frac{2M_v(6L-2f-3b) - 3V_v d^2}{144d^2(3L-2f-3b)}$$

Figure 5. Yield-Line pattern #2.



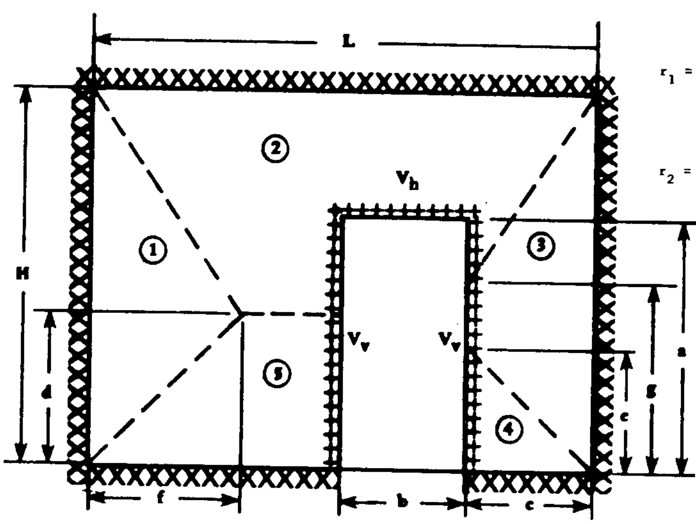
$$r_1 = \frac{M_H(3H+5z+5y) - 3V_v(H-z-y)\ell}{72\ell^2(3H-2z-2y)}$$

$$r_2 = \frac{10M_v\ell^2 - 6M_Hy^2 - 3V_v\ell y^2}{144\ell^2y^2}$$

$$r_3 = \frac{2M_v(3L+2\ell+5x) - 6M_H\left(\frac{z^2}{\ell}\right) - 6\,V_h(L-\ell-x)h + 3V_v(z^2-h^2)}{144[\ell z^2 + h^2(3L-3\ell-2x)]}$$

$$r_4 = \frac{10M_Hh - 6M_v\left(\frac{x^2}{h}\right) - 3V_hx^2}{144x^2h}$$

Figure 6. Yield-Line pattern #3.



$$r_1 = \frac{5M_H}{72f^2}$$

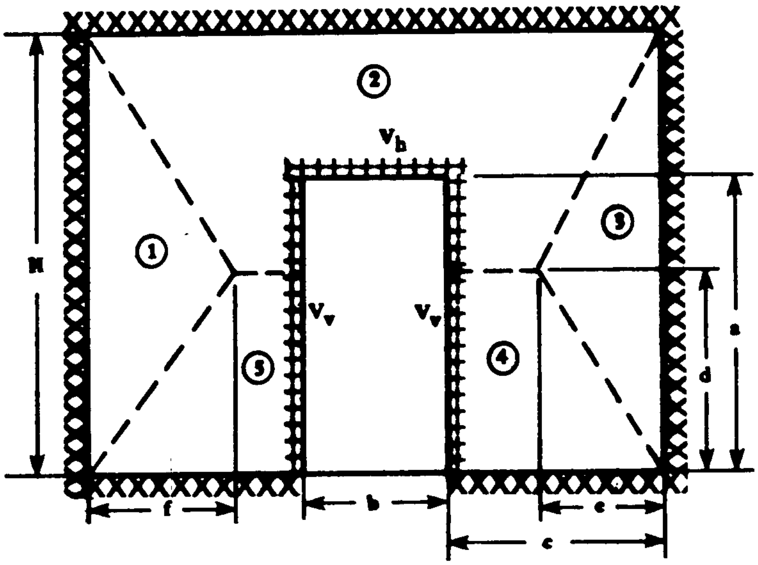
$$r_2 = \frac{M_v(12L-2f-2c-6b) + 6H_H\left(\frac{H-g}{c}\right)^2 + 6V_hb(H-a) + V_v[6H(2a-d-g)-6a^2+3d^2+3g^2]}{144[(H-d)^2(3L-2f-3b-3c) + 3b(H-a)^2 + c(H-g)^2]}$$

$$r_3 = \frac{M_H(8H-5g+5e) - V_v(g-e)c}{72c^2(H+2g-2e)}$$

$$r_4 = \frac{10M_vc - 6\left(\frac{e^2}{c}\right)M_H - 3V_ve^2}{144ce^2}$$

$$r_5 = \frac{2M_v(6L - f - 6b - 6c) - 3V_vd^2}{144d^2(3L - 2f - 3b - 3c)}$$

Figure 7. Yield-Line pattern #4.



$$r_1 = \frac{5M_H}{72f^2}$$

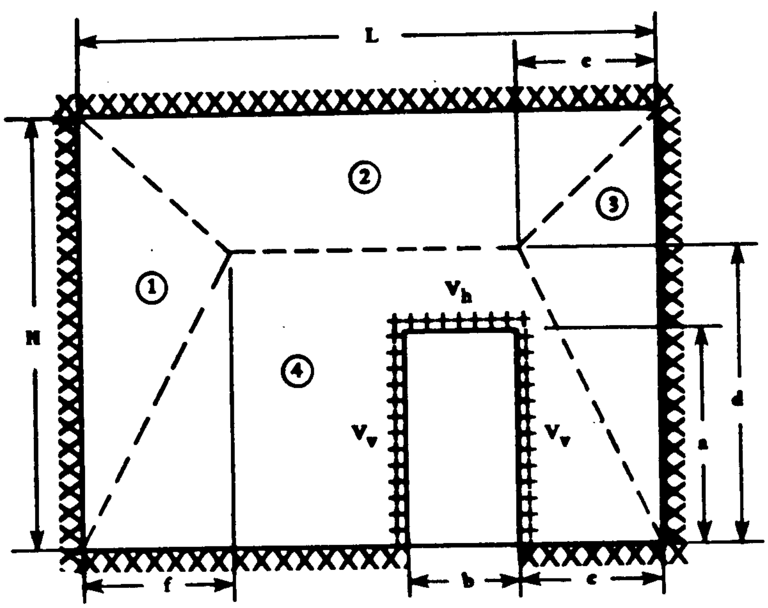
$$r_2 = \frac{M_v(6L-f-e-3b) - 3V_h b(H-a) - 3V_v(a-d)(2H-d-a)}{72[(H-d)^2(3L-2f-3b-2e) + 3b(H-a)^2]}$$

$$r_3 = \frac{5M_H}{72e^2}$$

$$r_4 = \frac{2M_v(6c-e) - 3V_v d^2}{144d^2(3c-2e)}$$

$$r_5 = \frac{2M_v(6L-f-6b-6c) - 3V_v d^2}{144d^2(3L-2f-3b-3c)}$$

Figure 8. Yield-Line pattern #5.



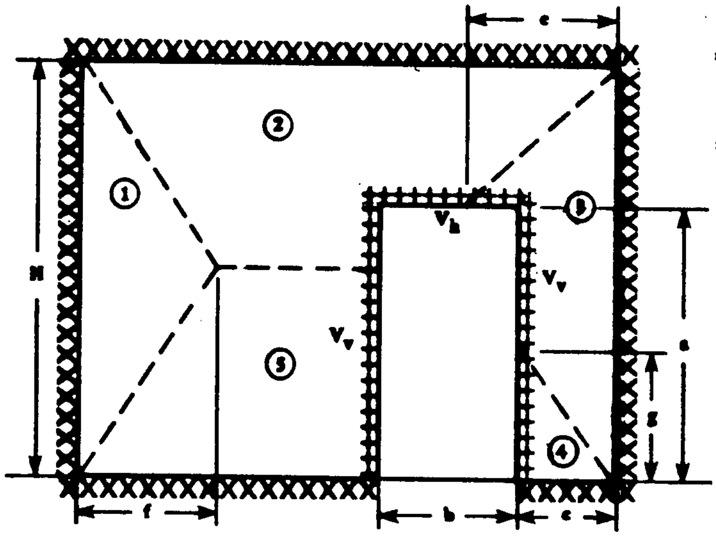
$$r_1 = \frac{5M_H}{72f^2}$$

$$r_2 = \frac{M_v(6L-f-e)}{72(H-d)^2(3L-2f-2e)}$$

$$r_3 = \frac{5M_H}{72e^2}$$

$$r_4 = \frac{M_v(6L-f-e-3b) - 3V_h ba - 3V_v a^2}{72[d^2(3L-2e-2f) - 3ba^2]}$$

Figure 9. Yield-Line pattern #6.



$$r_1 = \frac{5M_H}{72f^2}$$

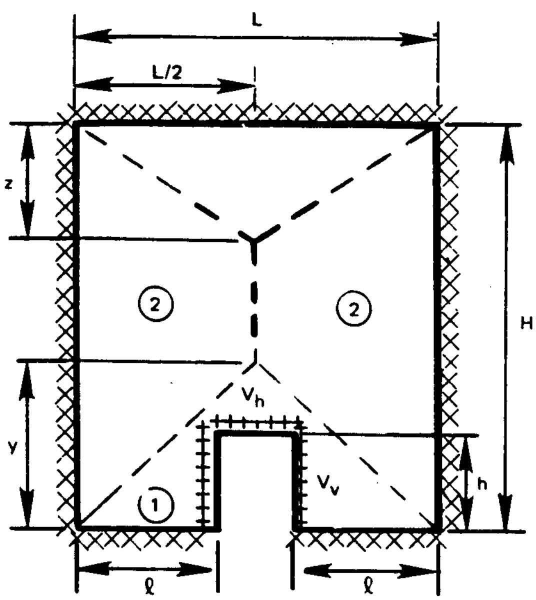
$$r_2 = \frac{2M_v(6L-f+5e-3b-3c) - 3V_v(a-d)(2H-a-d) - 6V_h(H-a)(b+c-e)}{144[(H-d)^2(3L-2f-3b-3c) + (H-a)^2(3b+3c-2e)]}$$

$$r_3 = \frac{2M_H(5H-2a+5g) - 6M_v\left(\frac{e^2}{H-a}\right) - 6V_v(a-g)c - 3V_h(e-c)(e+c)}{144[(H-a)e^2 + c^2(3a-2g)]}$$

$$r_4 = \frac{10M_vc - 3V_vg^2 - 6M_H\left(\frac{g^2}{c}\right)}{144cg^2}$$

$$r_5 = \frac{2M_v(6L-f-6b-6c) - 3V_vd^2}{144d^2(3L-2f-3b-3c)}$$

Figure 10. Yield-Line pattern #7.

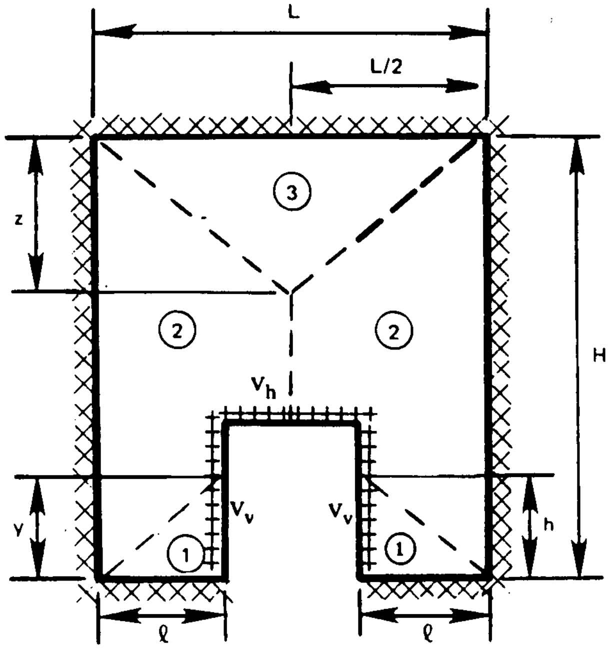


$$r_1 = \frac{2M_v(L+3\ell) - 3V_h(L-2\ell)h + 3V_vh^2}{72(Ly^2 - 3h^2L + 6h^2\ell)}$$

$$r_2 = \frac{M_H(6H-y-z)}{18L^2(3H-2y-2z)}$$

$$r_3 = \frac{5M_v}{72z^2}$$

Figure 11. Yield-Line pattern #8.

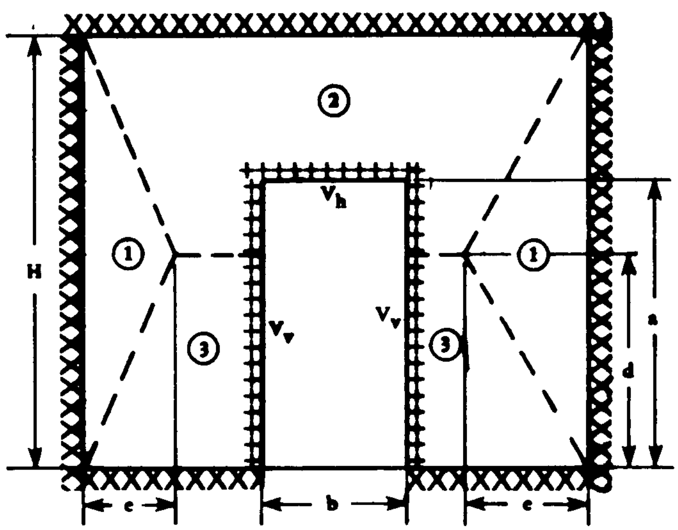


$$r_1 = \frac{10M_v\ell^2 - 3V_v\ell y^2 - 6M_H y^2}{144\ell^2 y^2}$$

$$r_2 = \frac{8M_H(6H-z-3h+5y) - 3V_h(L-2\ell)(L+2\ell) - 24V_h(h-y)\ell}{144[zL^2 + 3L^2(H-h-z) + 4\ell^2(3h-2y)]}$$

$$r_3 = \frac{5M_v}{72z^2}$$

Figure 12. Yield-Line pattern #9.

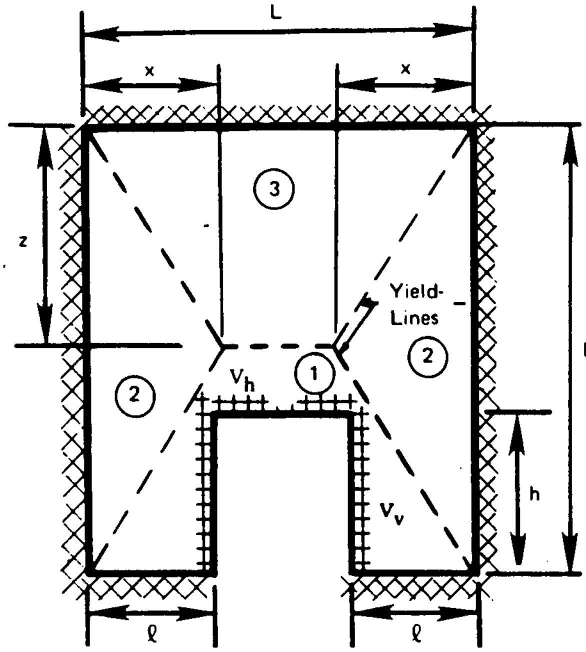


$$r_1 = \frac{5M_H}{72e^2}$$

$$r_2 = \frac{M_v(6L-2e-3b) - 3V_h b(H-a) - 3V_v(a-d)(2H-d-a)}{72[(H-d)^2(3L-4e-3b) + 3(H-a)^2 b]}$$

$$r_3 = \frac{2M_v(3L-3b-e) - 3V_v d^2}{72d^2(3L-3b-4e)}$$

Figure 13. Yield-Line pattern #10.

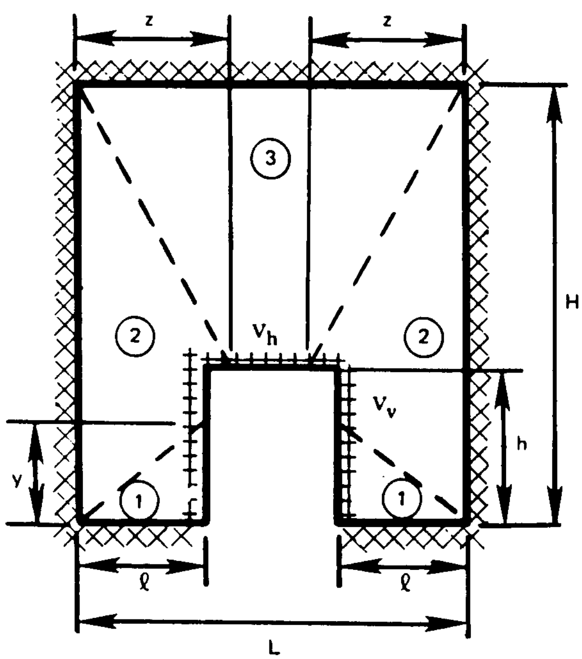


$$r_1 = \frac{M_v(6\ell+3L-2x) - 3V_v h^2 - 3V_h h(L-2\ell)}{72[2x(H-z)^2 + 3(L-2x)(H-z)^2 - 3h^2(L-2\ell)]}$$

$$r_2 = \frac{5M_H}{72x^2}$$

$$r_3 = \frac{M_v(3L-x)}{36z^2[2x + 3(L-2x)]}$$

Figure 14. Yield-Line pattern #11.



$$r_1 = \frac{10M_v\ell^2 - 6M_H y^2 - 3V_v y^2 \ell}{144\ell^2 y^2}$$

$$r_2 = \frac{2M_H(5H-2h+5y) - 6M_v\left(\frac{z^2}{H-h}\right) - 6V_v(h-y)\ell - 3V_h(z-\ell)(z+\ell)}{144[\ell^2(3h-2y) + z^2(H-h)]}$$

$$r_3 = \frac{M_v(7z+3L) - 3V_h(L-2z)(H-h)}{72(H-h)^2(3L-4z)}$$

Figure 15. Yield-Line pattern #12.

DESIGN AND EVALUATION OF ASSEMBLY BAY AND ASSEMBLY CELL COMPLEXES

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ABSTRACT

As part of the overall modernization and expansion of the Pantex Plant, Amarillo, Texas, the Department of Energy engaged the Joint Venture of Gibbs & Hill/Ammann & Whitney to design new Assembly Bay and Assembly Cell Complexes. As part of this design, the firm was required to develop and design modified Assembly Bay and Assembly Cell Structures based on the results of previously performed structural/explosive tests of similar structures. Both of these structures will be used for the assembly and inspection of components of explosive/hazardous items. This paper describes the analysis and design of the protective features of the facilities.

DESIGN AND EVALUATION OF ASSEMBLY BAY AND ASSEMBLY CELL COMPLEXES

Introduction

Design of the new Assembly/W80 Surge and Nuclear Weapons Stockpile Improvement (NWSI) Facilities consists of a complete Architectural/Engineering presentation of each area which includes architectural, civil, structural, electrical/electronic, fire protection, mechanical HVAC, plumbing and piping, radiological, and safety siting as required. However, this paper will deal primarily with the blast resistant structural and radiological aspects of the facilities design and, in particular, the design of the Assembly Bays and the Assembly Cells.

For this paper, the overall facility can be subdivided into three major sections (Fig. 1), namely: (1) Assembly/W80 Surve Bay Complex, (2) NWSI Bay Complex, and (3) combined Assembly/W80 Surge and NWSI Assembly Cell Complex. Each of these three areas is further divided into its component buildings as described below.

The Assembly/W80 Surge Bay complex includes the following areas; eleven (11) Assembly Bays, Linac Bay, Control and Film Process Rooms, Data Collection Room, Break Area, Mechanical and Electrical Rooms, four (4) Combustible Storage Rooms, Non-Combustible Storage Room and Secondary Electrical Room. All areas of the Assembly/W80 Surge Area are enclosed by a covered corridor around the periphery of the complex.

The NWSI Bay Complex is separated into the following areas; nine (9) Assembly Bays, Break Area, Mechanical and Electrical Rooms, four (4) Combustible Storge Rooms, Non-Combustible Storage Room, and Secondary Electrical Room. As in the case of the Assembly/W80 Surge Area all areas of the NWSI are enclosed by a covered corridor.

The Assembly Cell complex is divided into four Assembly Cells, Service Area, two (2) Mechanical/Electrical Areas and two (2) inconnecting ramps; one to the Assembly/W80 Surve Complex and one to NWSI Complex.

Since the subdivisions of the NWSI Bay Complex is very similar to the Assembly/W80 Surge Complex, this paper is limited only to the latter and this area is referred to as the Assembly Bay Complex.

Assembly Bay Complex

General

The explosive quantities in this complex are located in each of the eleven Assembly Bays and the Linac Bay. The quantity of explosive in each bay is equivalent to 390 pounds of TNT. No other areas of the complex

contain explosives. However, these other areas, except for the Storage area, house personnel and/or equipment which are required for the facility operation. These other areas have been designed as acceptor structures for a potential explosion in any one of the bays. Each bay contains operating personnel which will also require protection from an explosion in one of the adjoining bays. The hazard classification, of both the Assembly and Linac Bays, as defined in DOE Order 6430 (Ref. 1) is Class II cased explosion, specifies that personnel can be subjected to overpressures equal to or less than 15 psi.

Assembly and Linac Bays

All concrete elements and the structural steel blast doors of each Assembly Bay (Fig. 2) are designed to resist the blast and fragment effects produced by an explosion in an adjoining donor bay. The internal pressures within each bay, produced by an external explosion (explosion in a donor bay), will be less than the 15-psi criteria previously stated.

Each Assembly Bay is separated from an adjoining bay and the other buildings of the complex by a 13ft.-6in. layer of sand. The concrete walls and entrances of each bay will be severely damaged by an internal explosion, but will remain intact (Fig. 3). The amount of damage has been demonstrated by the results of both full and model scale tests (Ref. 2) of similar structures (Building 12-64 at Pantex).

The roof and doors are designed to be dislodged by the internal explosive effects and, thereby, relieve the internal pressures associated with the gas and temperature buildup produced by the accumulation of the particles of the explosion within the structure (Fig. 4). Although the blast doors and roof panel will not remain intact, their dislodgement is accomplished in a controlled manner. Wide flange structural steel members are embedded in the concrete roof and floor of the corridor adjacent to each door and this will prevent the blast doors from being projected away from the immediate vicinity of the donor bay. The roof of each bay is attached only at the front wall of the bay. In the event of an internal explosion, the roof will rotate above its point of connection and impact the earth cover over the entrance. The roof slab is designed not to disengage or to break up upon impact with the earth cover. The hinge point is formed by the lacing reinforcement which extends from the front wall into the roof slab (Fig. 5). The remainder of the structure is constructed of plain reinforced concrete. Fragments or missiles formed by the breakup of equipment will be trapped within the structure. The movement of the roof is very slow (several seconds to fully open), therefore, the internal fragments will overtake and impact the inner surface of the roof and be stopped. Fragments passing through the interlock area will be very low flying objects. These latter fragments will either impact the wide flange barrier or impact the ground immediately outside the bay corridor. High-speed missiles formed by the breakup of equipment in the donor bay will not penetrate the concrete walls and separating sand into the adjoining acceptor bays.

The Linac Bay is designed in a manner similar to the Assembly Bays. As a result of an explosion the roof of the Linac Bay will rotate and impact the earth mound adjacent to the bay area. The blast doors will be projected outward, but their flight will be limited by their impact against the reinforced concrete wall of an adjoining complex (Fig. 1).

Design for Blast Overpressures

Except for the Storage Areas, the surrounding corridor and the Fan Rooms above the Bay entrance, all sections of the Assembly Bay Complex will withstand the blast overpressures resulting from an explosion in a donor bay of the complex or an adjoining facility. Table 1 lists the blast overpressures which are generated within the donor bay as well as the blast loads acting on the exterior of the acceptor structures. The design precludes explosive propagation from bay to bay and prevents severe injury to personnel who are in occupied areas other than the bay in which the accident occurs.

Figure 6 illustrates predicted incident overpressure contours produced by an explosion within one of the protential donor bays. Development of the contours assumes that the major flow of the internal blast pressures, in a given donor bay, is through the building entrance rather than through the movable overhead roof slab. This phenomenon has been observed in the tests previously mentioned. To some extent, these contours account for the local dispersion effects of the blast overpressures. The blast pressures are amplified due to the shock front being diffused by the steel fragment shields located adjacent to the donor bay's blast doors. These effects tend to increase the incident blast overpressures acting on structures adjoining the donor structure.

It may be noted from Figure 6 that those areas within the Assembly Bay Complex immediately adjacent to the donor bay are subjected to overpressures greater than 15 psi. As previously mentioned, corridors around the complex as well as interconnecting ramps between complexes, Storage Areas and the Fan Rooms may fail due to the blast overpressures produced by an explosion in one of the bays. These facilities are considered as unoccupied and therefore, their collapse is acceptable.

Design for Blast-Induced Missiles

The occupied areas of the Assembly Bay Complex are protected from blast-induced missiles produced by the collapse of a donor structure. According to the safety criteria previously cited, the penetration of acceptor areas by; (a) primary or secondary fragments formed by the breakup of the explosive casing or equipment in the donor bay, (b) secondary missiles formed by the breakup of the donor structure, or (c) the generation of missiles within the acceptor structure by blast-induced motions or spalling of the acceptor structure interior, is considered as an acceptor building collapse. These criteria are extremely severe and therefore, in order to meet these criteria, formation of missiles of any

kind within an acceptor structure must be totally eliminated. Missiles formed within the donor structure as well as the missiles for which the acceptor structure has been designed to resist is listed in Table 2.

Secondary fragments formed from the breakup of equipment cannot escape from the donor bay. The structural steel fragment shields in front of the donor bay blast door will restrict the debris path of all large fragments and most small fragments through those openings. The small fragments which may pass between the structural steel wide flange sections will be low flying and will impact the ground surface immediately outside the structure. The slow movement of the roof slab will restrict secondary fragments from being projected overhead. Also, the thickness of the concrete and the sand fill between the donor and acceptor bays prevent high-speed fragments from perforating the acceptor bay. Results of the previously mentioned blast tests indicated that spalling of the donor wall of an acceptor bay will not occur due to an explosion in the adjoining donor bay.

The size of secondary concrete fragments produced by an explosion in one of the adjoining complexes is controlled. The size of each fragment is 1 foot square by 5 feet long. They are produced by the breakup of a donor bay roof. The roof of each occupied area of the complex is designed to resist the impact forces of the above fragments. An explosion in one of the other adjoining complexes will produce missile hazards no worse than those mentioned above.

Assembly Cell Complex

General

The explosives in the Assembly Cell Complex are located in each of the four Assembly Cells. The explosive quantity in each cell is equivalent to 550 pounds of TNT. The Service Area outside the four Cells and the Equipment Rooms are considered to be unoccupied areas and, therefore, do not require protection from an explosion, either in one of the cells or adjoining complexes. These latter buildings do not contain explosives. The hazard classification is as defined in DOE Order 6430 (Ref. 1) in each Assembly Cell as Class II uncased where total protection must be provided for personnel located exterior of a donor structure.

Assembly Cell

Except for the Entrance Corridor (Fig. 7), all concrete elements and the blast doors of each Assembly Cell are designed to resist the blast overpressures and fragment effects produced by an explosion in the Assembly Room. The concrete elements and blast doors are also designed to provide full protection for occupants from the blast overpressures and fragment effects of an explosion in adjoining donor cells or bays. The internal overpressure within each cell, produced by an external explosion, will be less than the 15 psi cited in the previously mentioned safety criteria.

Each Assembly Cell consists of an Assembly Room, where all explosive operations are performed; Tooling, Inert Parts, and Nuclear Material (SNM) Staging Rooms; Mechanical Room; and Equipment and Personnel Air Locks. The Equipment Air Lock is formed by two blast doors which seal the equipment entrance-way. The Personnel Entrance is protected by a structural steel revolving type blast door. Located within the Mechanical Room roof slab are three blast valves. These blast valves, each of which is positioned in either the air intake or exhaust ducts, will be closed by the blast overpressures produced by an internal explosion. The blast valves will remain closed after an explosion. The need for the blast valves is predicated by the internal blast overpressures which are produced by the "fall-back" of the gravel as described below.

The above areas have been designed to sustain the effects of an internal explosion. Pressure leakage will occur through the gravel above the Assembly Room (Fig. 8). Leakage will also occur through other openings including the ventilation intake and exhaust openings (prior to blast valve closure) as well as through small gaps around the blast doors. However, as shown from the recently performed tests of the Gravel Gertie (Ref. 3), the leakage pressures will be minimal.

An explosion can only occur in the Assembly Room where all hazardous operations are performed. For design purposes, the surface of the explosive has been assumed to be positioned at least three feet clear from the Assembly Room wall and two feet clear above the floor. Although the wall of the Assembly Room is designed to sustain relatively heavy damage, this one-foot thick wall in combination with the earth fill, will resist the blast load and will remain intact. The gravel fill above the Assembly Room wall will be projected upward due to the blast and thereby pressure "venting" the structure. This gravel will capture the major portion of the radioactive particles and prevent their escape to atmosphere. After the gravel has reached its maximum altitude due to the blast, it will "fall back" into the Assembly Room and thereby minimize any residual escape of contaminated particles through the opening above the Assembly Room.

Areas outside the Assembly Room (Staging Area) are designed to minimize through-cracking of the concrete walls. The concrete elements of the Staging Area utilized single leg stirrups to resist the high shear stresses produced by the internal blast loads. The concrete elements in combination with the earth-fill around the structure will prevent pressure leakage to the exterior.

Since the concrete portions of the structure are designed to minimize overpressure leakage to the exterior, the blast doors are also designed to resist the internal effects of the blast and fragments as well as to prevent major overpressure leakage to the exterior. The two blast doors which are used to seal the equipment entrance are mechanically and electrically interlocked to assure that at least one opening is sealed at all times. The personnel entrance is sealed with a revolving blast door.

Since the blast doors of both the equipment and personnel entrances are required to be operated manually and a step at the bottom of the door was not permitted, a complete seal around the closed blast doors cannot be maintained. Some pressure leakage will occur below the equipment doors and around the personnel door. The gaps around the doors have been limited to one-quarter inch below the equipment door, and one-half inch above and below and one-eighth of an inch along the sides of the personnel door. A small amount of radioactive particles will be carried to the exterior of the cell around the blast doors. However, these particles will be contained by the Service Area which will essentially remain intact after a detonation in the cell.

All electrical and mechanical penetrations through the concrete surfaces are protected from pressure leakage. Openings for HVAC equipment are protected by blast valves. In addition to preventing initial shock and gas pressure leakage, the valves will also prevent leakage of low level long duration pressures caused by "fall back" of the gravel fill. Other penetrations such as miscellaneous piping and conduit penetrations near the blast doors will provide leakage that will be relatively small or non-existent because of the pipe length to diameter ratios, the short duration of the shock loads, and/or blockage by liquid in the pipes or wires connected to equipment outside the cell.

The design blast overpressures and the structure response to these blast loads are listed in Table 3 while the design parameters for missiles are listed in Table 4.

Design for Blast Overpressure

Design of an Assembly Cell for internal explosions was described previously. This section deals with the design of the Cell for external overpressures.

Each cell is designed to withstand blast overpressures originating from an explosion in an adjoining cell or other surrounding explosive facilities.

The design of each cell precludes explosive propagation from cell to cell or from adjoining facilities to a cell. Personnel who are in occupied areas other than the cell where the accident occurs are protected from severe blast injury. Therefore, the cell design meets the safety criteria of limiting pressure exposure to personnel of 15 psi or less.

The predicted leakage overpressures through the gravel which are produced by an explosion within a donor cell, are very low. This was demonstrated in the Gravel Gertie blast tests which reported no significant pressure increase exterior of the structure (Ref. 3). These leakage overpressures will decrease rapidly with distance. Overpressures somewhat less than one psi may be expected to be acting on the Service Area due to an explosion in the cell.

Exterior overpressures produced by a donor bay in either of the two adjoining Acceptor Bay Complexes are illustrated in Figure 6. As seen, the largest incident overpressure acting on any cell is 3 psi or less. Therefore, leakage pressures into any one cell will be less than the 15 psi design criteria. On the other hand, the Service Area and Mechanical Rooms are not designed for blast overpressures. These areas of the Assembly Cell complex may be expected to be severely damaged by a detonation in one of the bays of the Assembly Bay Complex. However, these areas are unoccupied and blast protection is not required.

Design for Blast-Induced Missiles

The occupied areas of the Assembly Cell complex are the four Assembly Cells. Protection for the personnel located in these areas is required.

Secondary fragments formed by the breakup of equipment within a donor cell cannot escape from the donor structure. Fragments formed in the Assembly Room are confined by the overhead gravel and the concrete wall in combination with the sand fill around the structure. Fragments which are projected out the opening between the Staging Area and Assembly Room will impact the concrete wall located directly in front of the opening. Fragments which ricochet off the concrete walls and roof will be greatly reduced in velocity before reaching the blast doors. The thicknesses of the structural steel blast doors at the entrances are sufficient to resist penetration by the reduced velocity fragments.

If the explosion occurs within a donor bay of the Assembly Bay Complex (Assembly/W80 Surge Bay Complex), debris are formed by the dislodgment of the blast doors. In most cases, the flight of these debris is restricted by the fragment shields. However, in the case of the bay adjoining the crossover ramp between the Assembly Bay and Cell Complexes, this protection is not afforded. Blast doors from this bay will be projected outward at an initial velocity of 189 fps. The weight of each leaf is approximately 1055 pounds. The impact force produced by each door at a cell will be equal to 643,000 foot pounds. The blast door will strike the earth mound covering the cells. The magnitude of the impact force of any of the blast doors is not sufficient to penetrate the concrete of the Assembly Cell nor will they impact any of the blast doors.

In the event of an explosion in one of the bays whose roof will fail under controlled fragmentation, one or more of the 1-foot square by 5-foot long concrete missiles will impact one or more of the cells. The impact velocity is 97 fps. The exterior concrete of each cell is designed to resist this impact force while the penetration of one of the fragments into the overhead gravel will be 22 inches which is significantly less than the 21 -foot depth of the gravel.

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LIST OF TABLES

Table 1

STRUCTURE RESPONSE AND DESIGN BLAST LOADS (ASSEMBLY BAY COMPLEX)

			Donor Structure					Acceptor Structure					
Area Designation	Hazard Class	Building Contents (1)	Material of Construction (2)	Structural Response (3)	Average Roof Pressure (psi)	Gas Pressure (psi)	Support Rotation (degrees)	Roof Pressure (psi)	Source of Explosion	Personnel Protection	Equipment Protection	Explosives Protection	Structural Response
Assembly Bays	Class II Cased	P, E&E	RC	PC	466	110	N/A	2.9	Adjoining Bay	Yes	Yes	Yes	NC
Linac Bay	Class II Cased	P, E&E	RC	PC	233	93	N/A	2.9	Adjoining Bay	Yes	Yes	Yes	NC
Break and Office Area	N/A	Person	RC	N/A	N/A	N/A	N/A	2.9	Adjoining Bay	Yes	Yes	N/A	NC
Control and Film Process Area	N/A	Person and Equip.	RC	N/A	N/A	N/A	N/A	2.9	Adjoining Bay	Yes	Yes	N/A	NC
Data Collect Room	N/A	Person and Equip.	RC	N/A	N/A	N/A	N/A	2.9	Adjoining Bay	N/A	Yes	N/A	NC
Equipment Area	N/A	Equip.	RC	N/A	N/A	N/A	N/A	2.9	Adjoining Bay	N/A	Yes	N/A	NC
Combustible Area	N/A	Unoc'd	RC	N/A	N/A	N/A	N/A	N/A	Adjoining Bay	N/A	N/A	N/A	TC

Notes:

(1) P, E&E - Personnel, Equipment and Explosive.
Person and Equip - Personnel and Equipment.
Unoc'd - Unoccupied/Storage.

(2) RC - Reinforced Concrete; S - Structural Steel

(3) PC - Partial Collapse; TC - Total Collapse; NC - No Collapse

Table 1 (Cont'd)

STRUCTURE RESPONSE AND DESIGN BLAST LOADS (ASSEMBLY BAY COMPLEX)

			Donor Structure					Acceptor Structure					
Area Designation	Hazard Class	Building Contents (1)	Material of Construction (2)	Structural Response (3)	Average Roof Pressure (psi)	Gas Pressure (psi)	Support Rotation (degrees)	Roof Pressure (psi)	Source of Explosion	Personnel Protection	Equipment Protection	Explosives Protection	Structural Response
Non-Combustible Area	N/A	Unoc'd	RC	N/A	N/A	N/A	N/A	N/A	Adjoining Bay	N/A	N/A	N/A	TC
Fan Room	N/A	Unoc'd	S	N/A	N/A	N/A	N/A	N/A	Adjoining Bay	N/A	N/A	N/A	TC
Corridor	N/A	Unoc'd	S	N/A	N/A	N/A	N/A	N/A	-	N/A	N/A	N/A	TC

Notes:

(1) P, E&E - Personnel, Equipment and Explosive.
Person and Equip - Personnel and Equipment.
Unoc'd - Unoccupied/Storage.

(2) RC - Reinforced Concrete; S - Structural Steel

(3) PC - Partial Collapse; TC - Total Collapse; NC - No Collapse

Table 2

DESIGN FOR MISSILES
(ASSEMBLY BAY COMPLEX)

Area Designation	DONOR STRUCTURE				ACCEPTOR STRUCTURE			
	Building Missile		Equipment Missile		Building Missile(1)		Equipment Missile(2)	
	Mass	Velocity	Mass	Velocity	Penetration	Collapse	Penetration	Collapse
Assembly Bays	None	None	3"x4"x4"	3050 fps	1'-10"(3)	No	(4)	No
Linac Bay	None	None	3"x4"x4"	3050 fps	1'-10"(3)	No	(4)	No
Break and Office Area	N/A	N/A	N/A	N/A	1'-10"(3)	No	(4)	No
Control and Film Processing Area	N/A	N/A	N/A	N/A	1'-10"(3)	No	(4)	No
Data Collection Room	N/A	N/A	N/A	N/A	1'-10"(3)	No	(4)	No
Equipment Area	N/A	N/A	N/A	N/A	1'-10"(3)	No	(4)	No
Combustible and Non-Combustible	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fan Rooms	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Corridors	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Notes:

(1) 1'x1'x5' concrete missile formed by explosion in existing Building 12-84
(2) 3"x4"x4" structural steel missiles formed by explosion in Assembly or Linac Bay
(3) Penetration into sand cover
(4) Penetrated Donor Bay conc. wall and stop in sand between Donor and Acceptor Bays

Table 3

STRUCTURE RESPONSE AND DESIGN BLAST LOADS (ASSEMBLY CELL COMPLEX)

Designation	Assembly Cells	Service Area	Mech/Elect Rooms
Hazard Classification	Class II Uncased	N/A	N/A
Building Contents (1)	P,E&E	E	E
Donor Structure			
Material of Const'n (2)	RC&G	SS	SS
Structural Response (3)	PC	N/A	N/A
Avg. Wall Overpressure (psi)	1250	N/A	N/A
Gas Overpressure (psi)	125	N/A	N/A
Support Rotation (degrees)	5	N/A	N/A
Acceptor Structure			
Roof Overpressure (psi)	3.5	3.5	<3.5
Source of Explosion	Bldg 12-84	Bldg 12-84	Bldg 12-99
Personnel Protection	Yes	No	No
Equipment Protection	Yes	No	No
Explosive Protection	Yes	No	No
Structural Response (3)	PC	C	C

(1) P, E & E - Personnel, equipment and explosive
E - Equipment only
(2) RC&G - Reinforced Concrete and Gravel,
SS - Structural Steel
(3) PC - Partial containment, C - collapse

N/A - not applicable

Table 4

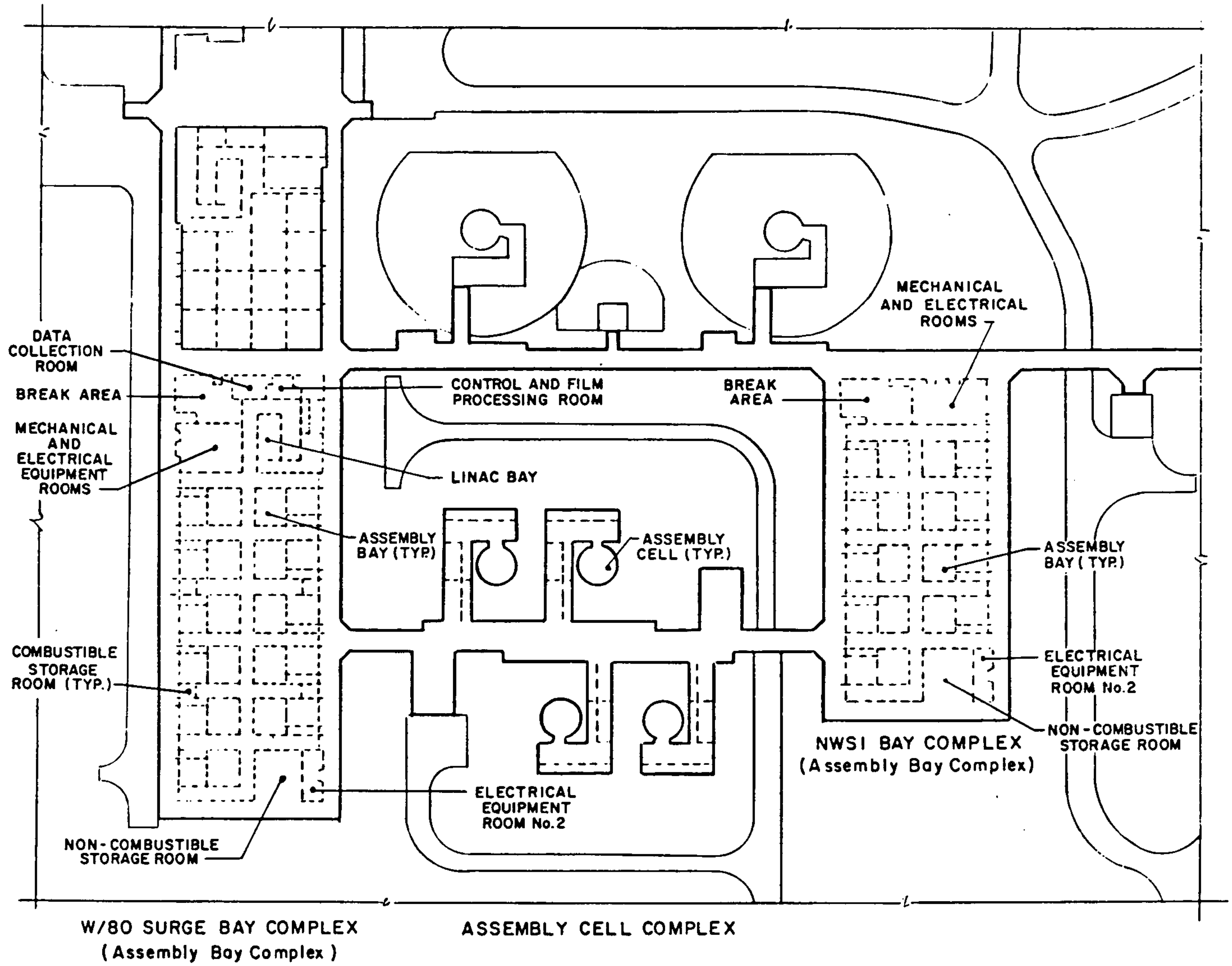
DESIGN FOR MISSILES
(ASSEMBLY CELL COMPLEX)

Designation	Assembly Cell	Service Area	Mech/Elect Rooms
Hazard Classification	Class II Uncased	N/A	N/A
Building Contents (1)	P, E & E	E	E
Donor Structure			
Bldg. Missile Mass	None	N/A	N/A
Bldg. Missile Vel.	None	N/A	N/A
Equip. Missile Mass	3" x 4" x 4"	N/A	N/A
Equip. Missile Vel.	3250	N/A	N/A
Acceptor Structure			
Conc. Frag. Mass (lbs) (2)	750	750	750
Conc. Frag. Vel. (fps)	97	97	97
Str. Response (3)	ND	C	C
Steel Frag. Mass (lbs)	1055	1055	1055
Steel Frag. Vel. (fps)	189	189	189
Structural Response	ND	C	C

(1) P, E & E - Personnel, Equipment and Explosive
E - Equipment
(2) Concrete fragment 1'x1'x5' (from roof of existing Bldg 12-84)
(3) ND - No damage, C - Collapse

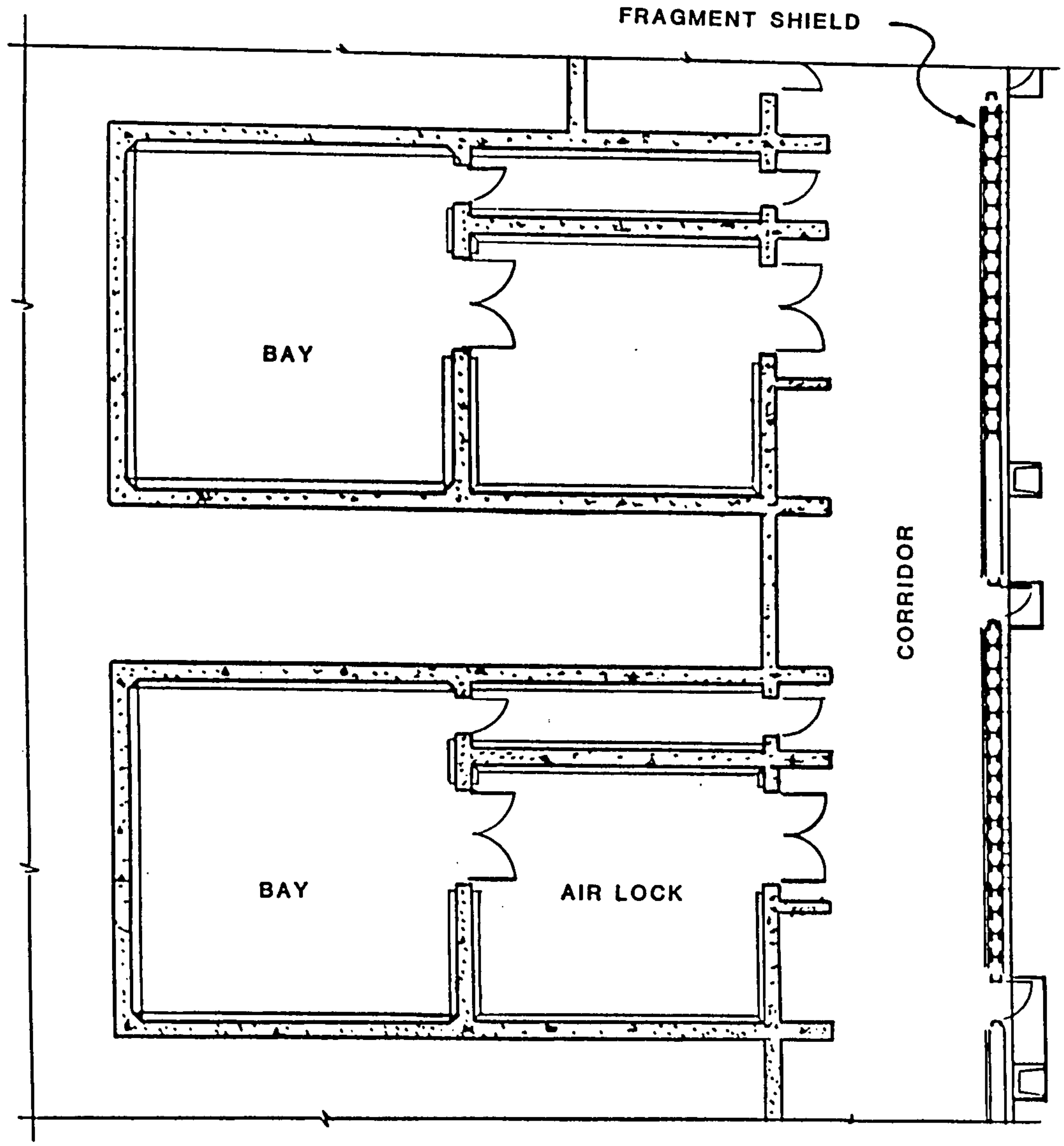
N/A - not applicable

LIST OF FIGURES



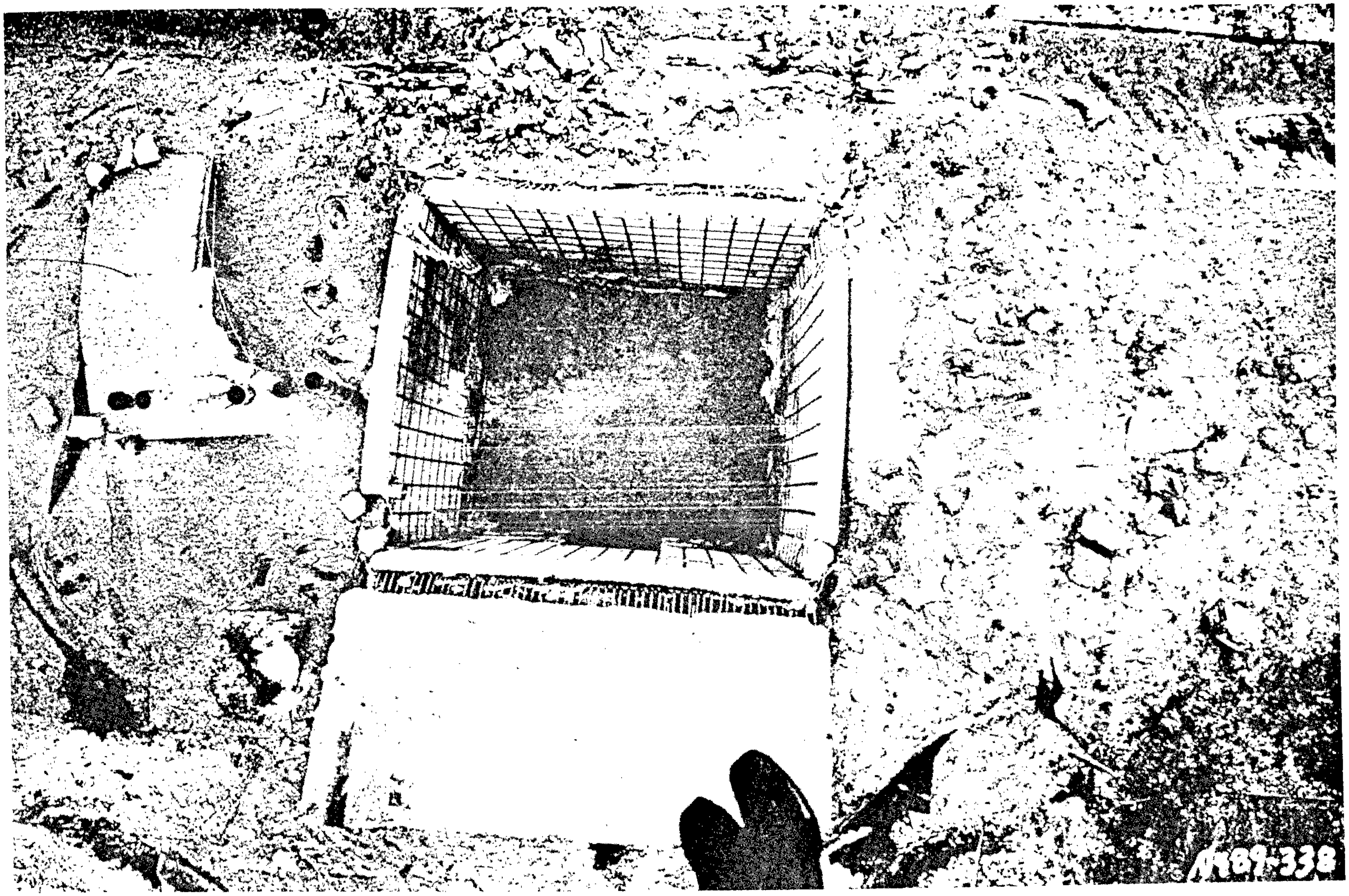
ASSEMBLY BAY AND CELL COMPLEXES

FIGURE 1



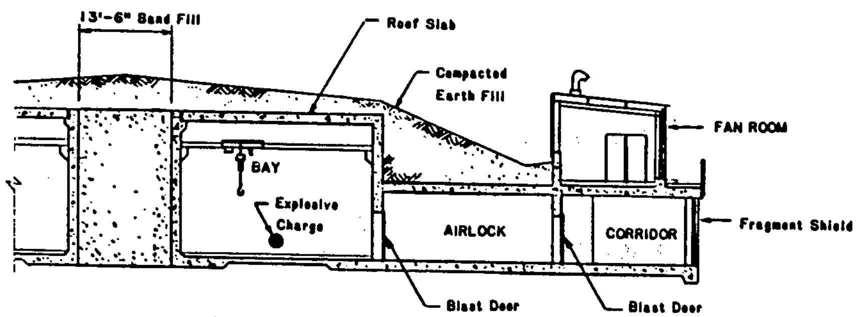
ASSEMBLY BAY FLOOR PLAN

FIGURE 2

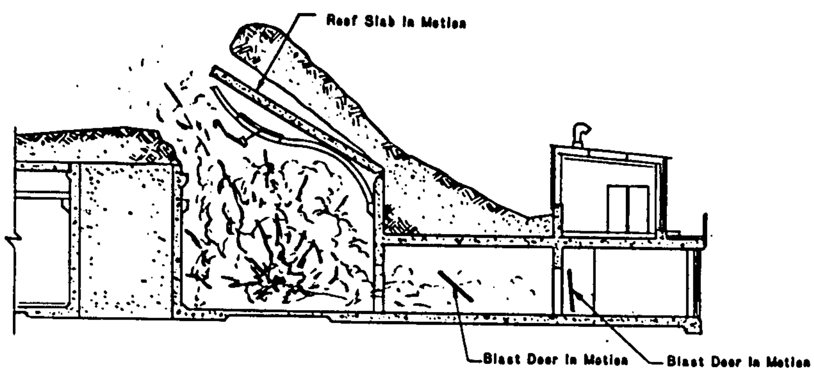


ASSEMBLY BAY TEST RESULTS

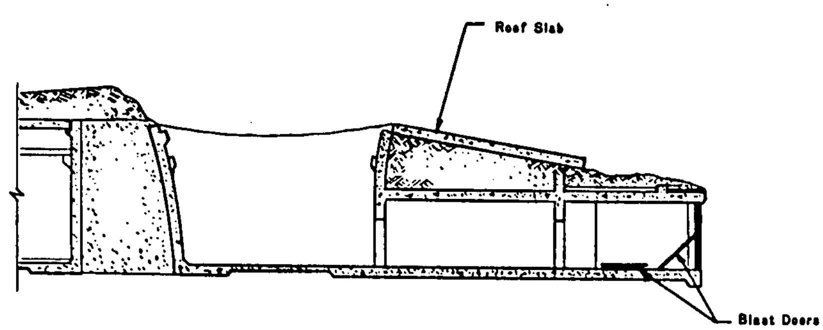
FIGURE 3



a. PRE-DETONATION



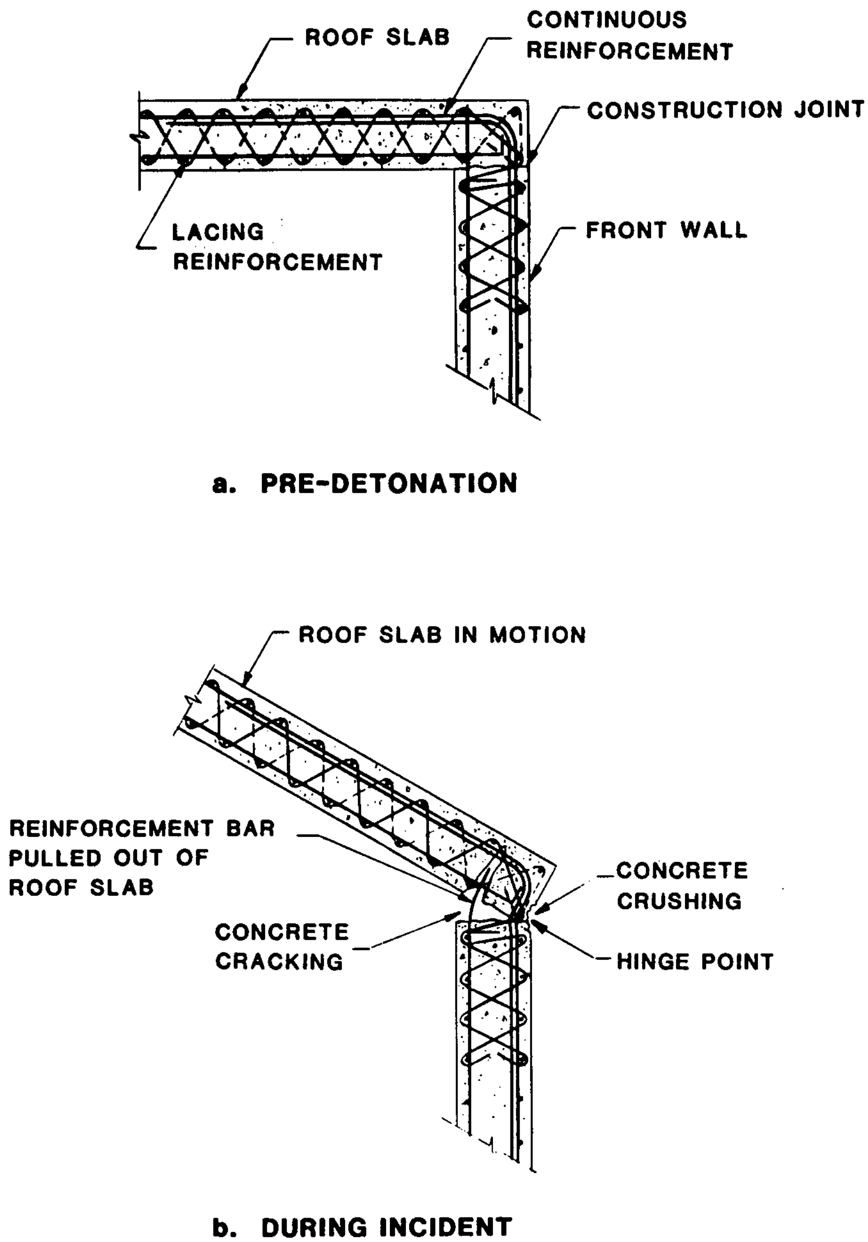
b. DURING INCIDENT



c. POST-DETONATION

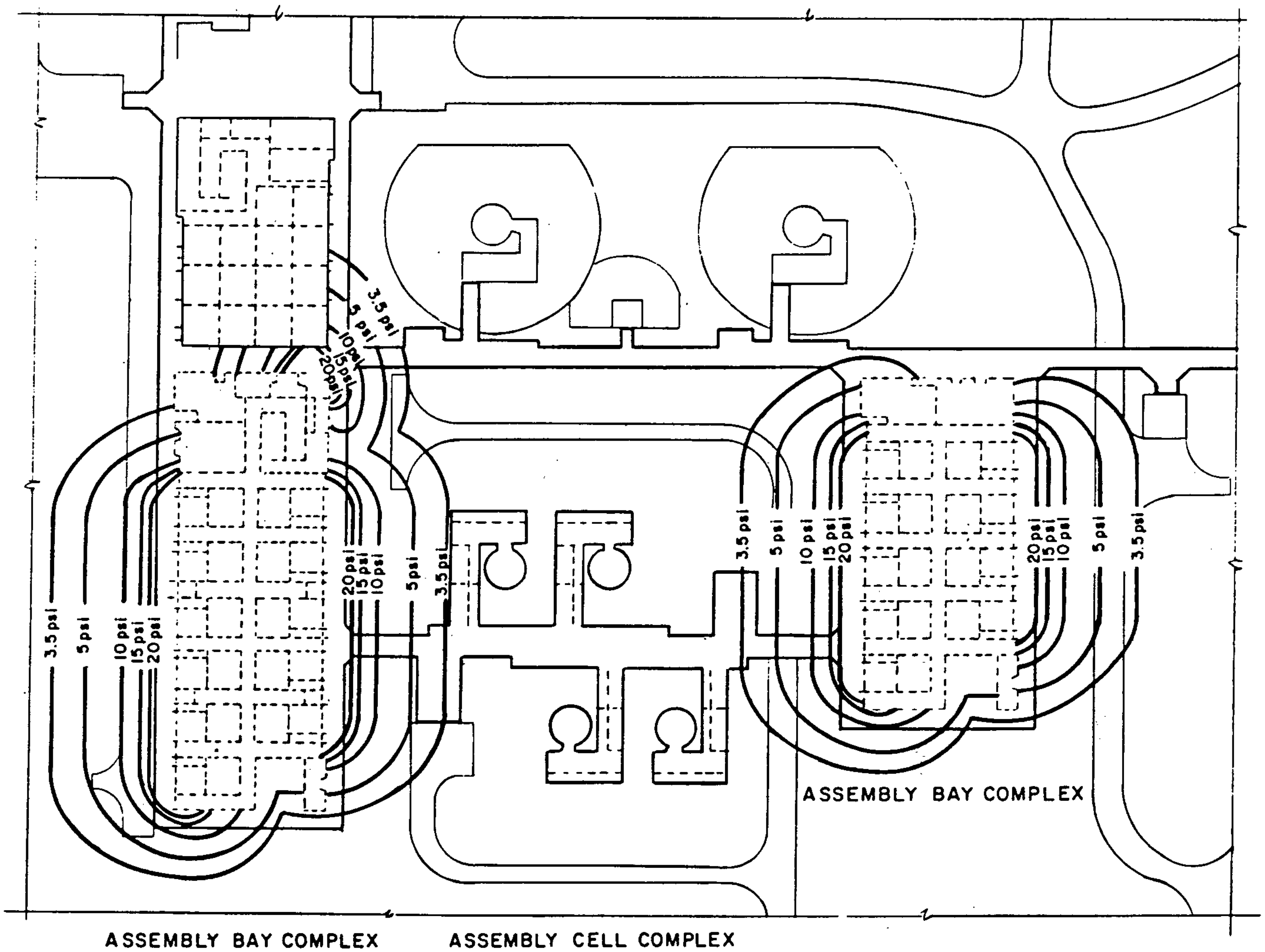
ASSEMBLY BAY PRESSURE RELIEF

FIGURE 4



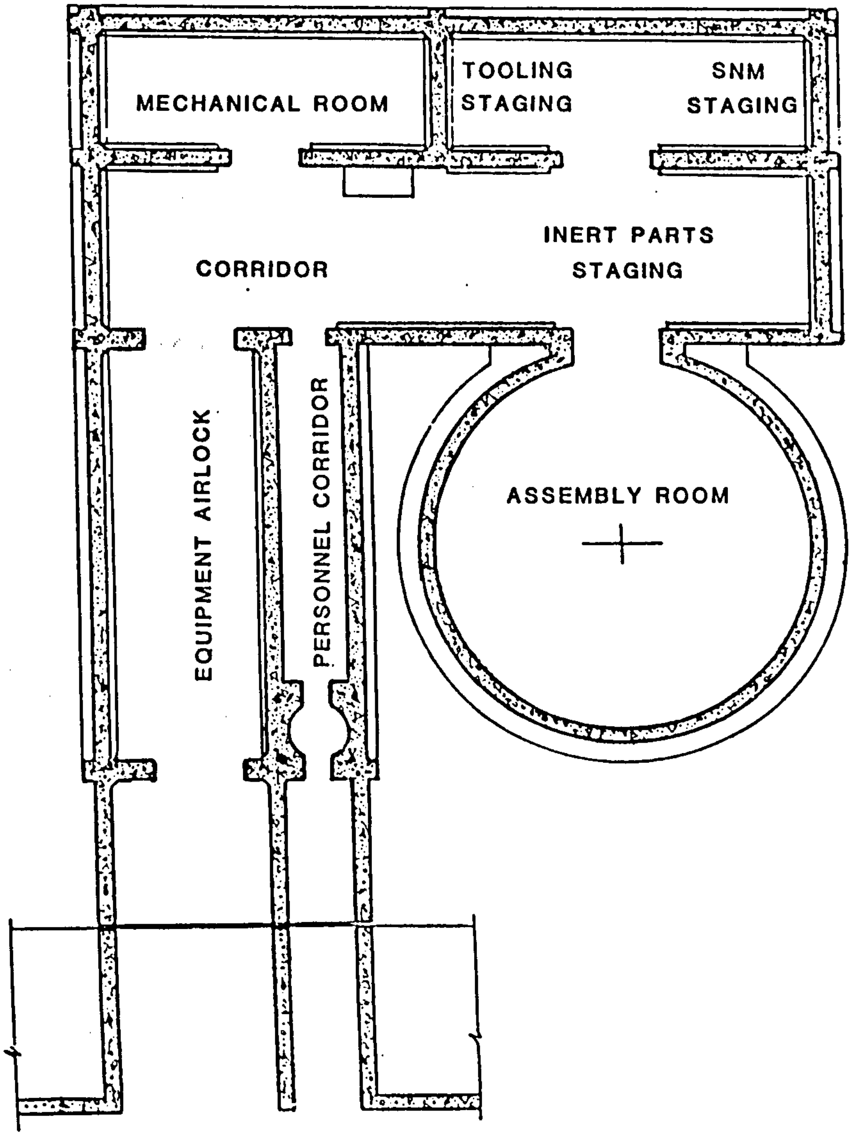
LACING DETAIL AT ROOF HINGE

FIGURE 5



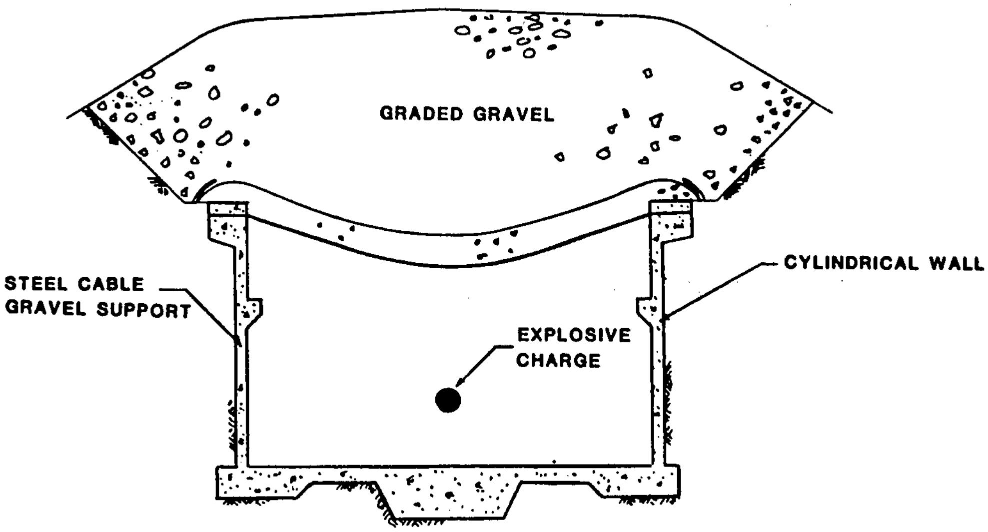
ASSEMBLY BAY LEAKAGE PRESSURE CONTOURS

FIGURE 6

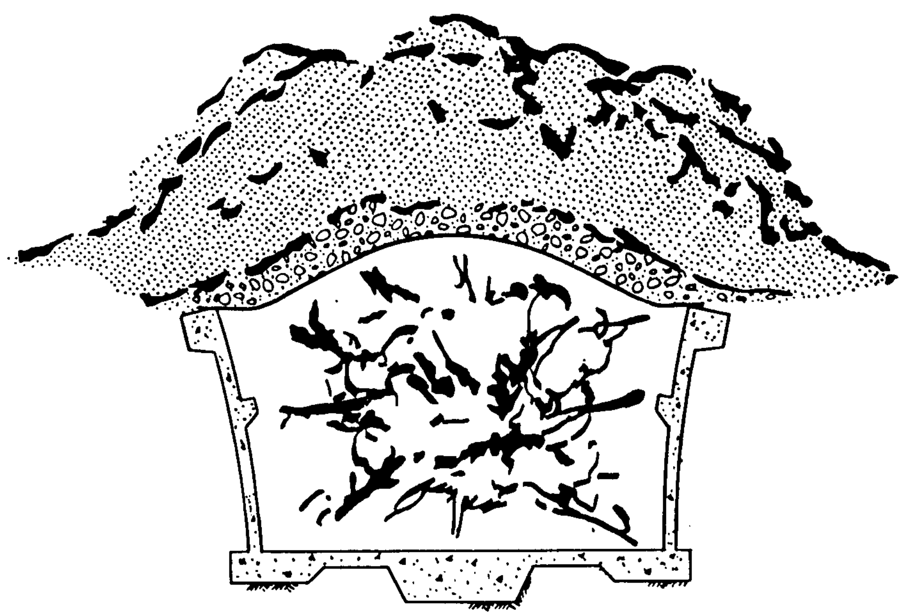


ASSEMBLY CELL FLOOR PLAN

FIGURE 7



a. PRE-DETONATION



b. DURING INCIDENT

ASSEMBLY ROOM PRESSURE RELIEF

FIGURE 8

BLAST-INDUCED MISSILE DESIGN

(ASSEMBLY BAY COMPLEX)

- **ACCEPTOR BAY COLLAPSE CRITERIA**

- PRIMARY OR SECONDARY FRAGMENTS FORMED IN DONOR BAY CANNOT PENETRATE INTO ACCEPTOR BAY

- SECONDARY FRAGMENTS FORMED BY BREAKUP OF DONOR BAY CANNOT PENETRATE INTO ACCEPTOR BAYS

- GENERATION OF MISSILES IN ACCEPTOR BAY DUE EITHER TO CONCRETE SPALLING OR SHOCK MOTION DISPLACEMENT OF EQUIPMENT IS NOT PERMITTED

- **ACCEPTOR BAY DESIGN**

- ESCAPE OF PRIMARY OR SECONDARY MILLILES ARE PREVENTED BY ROOF SLAB AND FRAGMENT SHIELD

- CONCRETE AND EARTH FILL THICKNESS WILL RESIST FRAGMENT PENETRATION

- EXPLOSIVE TESTS INDICATE CONCRETE SPALLING OF ACCEPTOR BAYS WILL NOT OCCUR

- EQUIPMENT SUPPORTS IN ACCEPTOR BAYS ARE DESIGNED TO RESIST STRUCTURE MOTIONS

- BAY ROOF CAN RESIST IMPACT FORCE OF A CONCRETE FRAGMENT (1 FOOT SQUARE BY 5 FEET LONG)

REVISION OF THE DESIGN MANUAL
"STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS"
(TM 5-1300, NAVFAC P-397, AFM 88-22)

Joseph Caltagirone, Angelo Castellano, ARDC

Michael Dede, Norval Dobbs, Ammann & Whitney

ABSTRACT

Procedures for structures designed to resist the effects of HE type explosions are presently available in the Tri-Service Design Manual "Structures to Resist the Effects of Accidental Explosions" (TM 5-1300, NAVFAC P-397, AFM 88-22). However, these procedures are limited to reinforced concrete structures. Since its original publication, a considerable amount of data has been generated which brought about the requirement to revise existing procedures in the manual and incorporate new data. This paper describes the format of the revised manual and provides a discussion on the contents of each of the six volumes, including the improvements made to the existing manual.

STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS (TM 5-1300, NAVFAC P-397, AFM 88-22)

INTRODUCTION

Initial guidance in the highly specialized and complex field of protective design against detonation effects produced by HE or similar type explosives and/or explosive like materials was furnished in 1969 when the design manual "Structures to Resist the Effects of Accidental Explosions" (Ref. 1) was published as a Tri-Service Manual. However, this Manual was limited primarily to the design of reinforced concrete structures. Since its original publication, a considerable amount of data has been generated. This data formed a basis for the development of design criteria for new materials as well as updating the design criteria for reinforced concrete. This new criteria along with additional data on blast parameters has necessitated a revision to the Manual.

The revision to "Structures to Resist the Effects of Accidental Explosions" is divided into six volumes (fig. 1):

Volume	I	-	Introduction
Volume	II	-	Blast, Fragment, and Shock Loads
Volume	III	-	Principles of Dynamic Analysis
Volume	IV	-	Reinforced Concrete Design
Volume	V	-	Structural Steel Design
Volume	VI	-	Special Considerations in Explosive Facility Design

The material contained in each of these volumes will be described later in this paper.

In addition, repositories which contain computer programs that are consistent with the procedures and techniques contained in the new Manual are being established at a specific location for each of the three armed services. Limited number of copies of the programs will be available from each repository upon request. The individual programs will be identical at each repository. These programs will be continuously updated or revised as required.

VOLUME CONTENTS

Volume I - Introduction

The data contained in Volume I will essentially consist of an expanded discussion of the topics presently contained in Chapter 1,2 and 3 of the present verison of the Manual (fig. 2). Specific items which are covered include: background for the Manual, scope and format, safety factor and accuracy, description of an explosive protective system, protection categories, and acceptor sensitivity. Regarding the latter there will be an extensive increase in data regarding such areas as human tolerance to both blast overpressures and shock, explosive initiation by fragments and equipment tolerances to shock loads.

Volume II - Blast, Fragment and Shock Loads

As the title indicates, this volume is divided into three main sections (fig. 3); that is, (1) blast loads acting on protective structures which are produced by the impact of the blast pressure output of the explosion, (2) primary and secondary fragments associated with the breakup of the explosive casing and equipment in close proximity to the detonation, and (3) shock loads which are associated with the protective structure motions casued by the impact of the blast overpressures and/or ground motion.

Blast Loads - Blast loads are divided into three main categories depending on the confinement of the explosion (fig. 4), namely; unconfined explosions, vented explosions and confined explosions. Blast parameters, which are associated with these various loadings, are presented. These parameters are based on the most recent data available.

Blast loads associated with unconfined explosions are further divided into free air burst loads, air burst loads and surface burst loads. These loading conditions are usually applicable to the design of shelter type structures which are subjected directly to the blast output of the explosion.

Vented explosions refer to those detonations which occur next to a barricade or some other obstruction or within a cubicle type structures which permits total venting of the explosive effects. Loadings associated with vented explosions are classified as exterior (or leakage) pressure loads or interior (or high) pressures. Exterior pressure loads are usually involved in the design of shelter structures, while interior pressures are required to design the protective structure close to the explosion source. Because of the relatively large venting effects of the structure, the duration of the internal loads are generally short (on the order of milliseconds).

Blast loadings corresponding to confined explosions are similar to those of vented explosions except that additional long duration loadings will occur within the containing structure. These latter loads are referred to as quasi-static or gas pressures and are produced by the accumulation of the gaseous products of detonation as well as the temperature rise within the confining structure. The magnitude of the gas pressures are presented to determine the magnitude and duration of the shock pressures, as well as the duration of the gas pressures as a function of building frangibility.

In addition, procedures are available for determining blast loads acting on rectangular shelter type structures as well as for determining leakage into shelter type structures.

Fragments - Fragment generation from explosions consist of primary fragments formed by the fragmentation of the explosive casing or container and secondary fragments formed by the break up of equipment (machinery, small tools, piping, lumber, etc.) located in the general vicinity of the explosions.

Procedures, for primary fragments are presented for determining fragmentation patterns and weight of the largest fragment resulting from a

high-order detonation as well as the initial velocity of the fragment. In addition, procedures are presented for determining variation of fragment velocity with distance away from the explosion.

As previously mentioned secondary fragments are missiles formed by the breakup of equipment or other elements located in the vicinity of an explosion. Procedures are available for determining fragment velocities for both unconstrained and constrained fragments. Also presented are methods for determining distance which secondary fragments will be projected as well as impact velocities and fragment distribution.

Shock Loads - The blast loading effects are the governing factor in selecting the structural configurations of buildings adjoining an explosion. However, structure motions produced by the blast can be a significant consideration in determining the overall blast resistant capabilities of the adjoining buildings. This is particularly true where personnel and/or equipment are located in the acceptor structure.

When an explosion occurs close to or on the ground, shock waves are transmitted through the air and ground. The movement of acceptor structures associated with the shock transmitted through the ground is referred to as ground-shock-motion while movement of the structure caused by the shock wave in the air is called air-blast-motion.

Ground shock motions may be subdivided into ground induced motion and air induced motions. Ground induced motions are caused by the shock wave which is transmitted directly through the ground from the explosion to the acceptor building in question while the air-induced-motions are associated with effects which are induced into the ground by the blast wave on the ground surface. The effects of the air-and-ground-induced motions may or may not be additive depending on the arrival time of the individual waves at the building in question. Ground shock effects are associated with both the vertical and horizontal motions of the ground.

When the shock wave, which is travelling along the ground, impinges on an acceptor structure, the transient effects of the air blast across the structure will cause unbalanced loads to be formed on the structure and thereby produce a sliding effect between the structure and the ground. This is referred to as air-blast motion. The motion of the building relative to the ground is a function of the restraint between building and ground. When a building is constructed on a foundation slab, the only restraint is afforded by the friction which will be developed between the slab and ground. Depending on the magnitude of the unbalanced force on the building, sliding may or may not occur. For example, when the building requires a deep foundation, the restraint between the building and the ground will be such that the movement of the building will be the same as that of the ground. The predominant effect of air-blast-motion is the horizontal movement of the building. The vertical movement due to air-blast-motion will have minimal effects on the structure.

Procedures are presented for determining the motions caused by ground shock and air blast effects are well as the interaction of both effects. Also, procedures are presented for determining shock spectra which may be used for evaluation of structure motions as well as the design of shock isolation systems.

Volume III - Principles of Dynamic Analysis

Data on principles of dynamic analysis as presented in the existing Manual has been extensively supplemented and expanded to cover a more complete range of possible structural response situations. Data for determining resistance-deflection functions and crack line locations has been significantly increased in the new Manual as compared to the present Manual. This data expansion has been extended to include the determination of elastic and elasto-plastic moment and deflection coefficients for various support and loading conditions including both one-and two-way elements as well as flat slabs.

As in the present Manual, the new Manual utilizes the single-degree-of-freedom method to represent the motions of the actual structure subjected to blast loads. The utilization of the single-degree-of-freedom method requires the establishment of dynamic design or transformation factors. Procedures for determining these factors, which include the load, mass and resistance factors or as an alternative the load-mass factors, are presented. Transformation factors are presented for one way members having variable loadings while load-mass factors are presented for various two-way spanning elements.

Two design charts are presented in the present Manual for determining structure response to blast overpressures. One chart pertains to structure response to direct loading while the second is used to determine rebound forces. The number of design charts furnished in the new Manual has been increased to 216 and covers maximum elastic response to triangular loads, rectangular loads, gradually applied loads, triangular pulse loads and sinusoidal loadings. The new charts also cover maximum response to elasto-plastic systems including triangular loads, rectangular loads, gradually applied loads, triangular pulse loads and bilinear-triangular loads as well as rebound forces.

In addition to the expanded section on design charts the new Manual contains procedures for performing numerical integration means of analyses. These analyses include both the average-acceleration-method as well as the acceleration-impulse-extrapolation-method. Procedures are presented for including damping in a system as well as for analyzing two-degree-of-freedom systems.

The analyses performed by either the chart method or numerical integration are generally applied to the analysis of structures that respond to either the peak pressure or the pressure-time history of the blast environment. However, some elements can be considered as responding only to the impulse (area under the pressure-time curve) of the blast loads. Design procedures are available in the new Manual to analyze these systems.

The outline of the contents of Volume III is listed in Figure 5.

Volume IV - Reinforced Concrete Design

The technical data in the volume for the design of concrete structures has been greatly expanded from the previous edition (fig. 6). Not only has the existing data been expanded, a considerable amount of new data has been

added. This additional data will facilitate the design of more cost effective structures by eliminating conservativeness resulting from a lack of data.

The existing Manual is concerned primarily with the design of laced reinforced concrete walls to resist the effects of close-in detonations. Some data is included for the design of slabs to resist the blast effects of intermediate and far range explosions. A well informed individual could adapt and expand this considerable amont of data to other design problems. This new volume includes new design procedures to enable the not so informed individual to prepare realistic and cost effective designs.

The new edition of the Manual provides a better estimate of the dynamic capacity of both the concrete and reinforcing steel than the present Manual. Based on recent research and testing, the dynamic increase factors for both concrete and reinforcing steel are presented as a function of the actual response of the structural elements as well as the values needed for design. In addition, the static yield strength of the reinforcement is increased 10 percent beyond the minimum specified by the ASTM to account for the actual strength steel that is furnished by the steel producers. Finally, the shear capacity of concrete elements as presented in the current Manual has proved to be conservative. Therefore, the new edition deletes the capacity reduction factor applied to the shear capacity of concrete.

The design for close-in blast effects is concerned primarily with the design of laced concrete elements. Laced concrete walls can be designed for deflections ranging from small to larger to incipient failure conditions and beyond to the design of post-failure fragments. However, for small deflections (less than 2 degrees support rotation) procedures have been included for the design of slabs reinforced with single-leg stirrups rather than lacing. This type of shear reinforcement will greatly simplify construction and should result in considerable cost savings.

Conventionally reinforced concrete elements were not extensively treated in the existing Manual. Only a limited amount of data was presented for the design of one and two-way elements. This new edition greatly expands this data to include design procedures for slabs and walls of various support conditions, as well as design procedures and deflection criteria for beams and both interior and exterior columns. The design of slabs include not only one and two-way slabs of various support conditions but also includes the design of flat slabs. Also, when support conditions permit, tension membrane action of the slabs is incorporated in the design. The inclusion of this membrane actions permits the slab to attain relatively large deflections at reduced strength and thereby resulting in substantial cost savings.

The structural design for brittle mode response contains most of the data from the previous Manual. However, prediction curves for the occurrence of spalling of concrete is included. These curves will more realistically predict the need for costly structural steel spall plates. In addition, the structural behavior to primary and secondary fragment impact is expanded.

The new edition of the Manual contains a chapter on foundation design. The data presented will enable the designer to predict the gross motion of structures subject to overturning. The structure motion is based on rigid body motion to predict soil-structure interaction.

The last portion of this volume greatly expands the detailing procedures presently incorporated in the Manual. The existing Manual provides details for laced construction. These details are expanded to include information acquired from numerous construction projects. Detailing procedures are provided for conventionally reinforced concrete, elements incorporating either single leg stirrups or lacing, flat slabs, beams columns and foundations.

Volume V - Structural Steel Design

The mechanical properties of structrual steel elements are presented in this volume along with recommended dynamic design stresses and acceptable maximum displacement, and plastic deformations (fig. 7) within the broad range of steel presently available. The structural steels for plastic design covered by the AISC Specifications are reviewed with regard to their uses in protective structures subjected to blast loads. The effects of rapidly applied dynamic loads on the mechanical properties of steel as a structural material are considered and these effects are related to the response of the component elements of steel structures. Design concepts for blast resistant steel structures are discussed in detail in order to provide the designer of modern explosive facilities with an overall understanding of the modes of failure of steel structures.

Procedures are presented for the design of beams and plates. These design procedures include design for flexure, shear and local buckling of elements including web crippling and lateral bracing. Procedures are presented for columns and beam-columns (columns with axial and lateral load), blast doors and cold-formed steel panels.

A method for performing preliminary blast load design of structural steel frames is presented. This analysis requires the determination of the flexural capcacities of individual members. The analytical procedures can consider both single and multi-bay arrangements for both rigid and braced frames. Based on the results of the preliminary analysis, a final frame analysis can be performed. Several computer programs are available to perform a step-by-step numerical integration of the frames.

A section is also provided which outlines methods of detailing connections for structural steel.

The data presented so far pertains to steel structures subjected to intermediate or low pressure ranges. Data is also presented for structural steel which is located very close to the explosion where fracture design is required.

Volume VI - Special Considerations in Explosive Facility Design

This volume is divided into nine subsections, namely: (1) masonry design, (2) precast concrete design, (3) special provisions for pre-engineered buildings, (4) suppressive shielding, (5) blast resistant windows, (6) design loads for underground structures, (7) earth-covered arch-type magazines, (8) blast valves (9) shock isolation systems (fig. 8). Each one of these subsections is independent of one another and, therefore, could have been

placed in separate volumes. However, because the shortness of each section and in some cases incompleteness because of the reference to other Manuals, it was desired to combine these sections into one volume.

Masonry Design - This section describes the procedures for design of masonry walls subjected to blast overpressures. Methods are included for construction of blast resistant masonry walls. Included in the design procedures are methods for calculating the ultimate strength of masonry walls as well as resistant-deflection functions. Design criteria is presented for allowable deflections.

Precast Concrete Design - Described in this section are the procedures used for design of precast elements subjected to blast overpressures. Methods are included for construction of precast concrete slabs, beams and columns. The design procedures include methods for calculating ultimate resistance and resistance-deflection functions as well as deflection criteria. Procedures are presented for analyzing precast elements.

Special Provisions for Pre-Engineered Buildings - Standard pre-engineered buildings are usually designed for conventional loads (live, snow, wind loads, etc.). Blast resistant pre-engineered buildings are also designed in the same manner as standard structures. However, conventional loadings, which are used for blast resistant design must be somewhat larger than conventional loadings to compensate for the effects of the blast loads. This section presents the magnitude of these larger conventional loads as well as present details of both the main frame members and foundations which must be incorporated into the building design. Also presented is a recommended specification for pre-engineered buildings which are to be hardened.

Suppressive Shielding - Presented is a summary of design and construction procedures which are outlined in the design Manual, titled "Suppressive Shields - Structural Design and Analysis Handbook"(HNDM 1110-1-2). This section describes the application of suppressive shielding as well as design criteria and procedures. Methods of designing equipment penetrations through walls as well as blast doors to be used with suppressive shielding are discussed.

Blast Resistant Windows - Historically, explosion effects have produced airborne glass fragments from failed windows which are a risk to life and property. Guidelines are presented for the design, evaluation and certification of windows to safely survive a prescribed blast environment. Design criteria is presented for both glazing and window frames. The design procedures include a series of design charts for both the glazing and frames.

Design Loads for Underground Structures - This section is a summary of the data presented in the design Manual, "Fundamentals of Protective Design for Conventional Weapons" (TM5-855-1). The data contained in this Manual pertains primarily to effects produced by explosions on or below the ground surface and the blast pressures they produce on below ground structures. Procedures are presented for evaluating blast loads acting on the structure surface as well as structure motions caused by explosions.

Earth-Covered Arch-Type Magazines - This section deals with typical earth-covered magazines which are used for storage of explosives. Included are

requirements for both metal arch and reinforced concrete arch magazines including semicircular and oval types. Discussed are the investigations performed in connection with magazines, design procedures, construction and standard designs.

Shock Isolation Systems - Data presented for shock isolation systems has been greatly expanded from that given in the present Manual. The data given in the present Manual is basically qualitative rather than quantitative. Although a full discussion of the subject is beyond the scope of the Manual, an introduction to isolation system design is presented. Included are various methods of achieving shock isolation for both equipment and personnel. Typical designs for equipment supports are presented.

Blast Valves - This section discusses several types of blast valves that are available commercially, including sand filters, hardened louvers and poppet valves. Also presented are the advantages and disadvantages of blast-actuated vs remote-actuated blast valves, the effect of plenum chambers, and a sample set of specifications for the design, testing and installation of a poppet valve.

REFERENCES

1. Structures to Resist the Effects of Accidental Explosions; Department of the Army Technical Manual, TM5-1300; Department of the Navy Publication, P-397; and Department of the Air Force Manual, AFM88-22, June 1969.

2. Suppressive Shields - Structural Design and Analysis Handbook, HNDM 1110-1-2, prepared by Civil/Nuclear Systems Corporation, Albuquerque, NM; under Contract DACA-87-76-C-0057, prepared for U.S. Army Corps of Engineers, Huntsville Division, Huntsville AL; monitored by Chemical Systems Laboratory, Aberdeen Proving Ground, MD, 18 November 1977.

3. Fundamentals of Protective Design for Conventional Weapons, TM5-855-1, prepared by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, for Office, Chief of Engineers, U.S. Army, Washington, D. C.

STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS
(TM 5-1300, NAVFAC P-397, AFM 88-22)

MANUAL CONTENTS

VOLUME I	-	INTRODUCTION
VOLUME II	-	BLAST, FRAGMENT AND SHOCK LOADS
VOLUME III	-	PRINCIPLES OF DYNAMIC ANALYSIS
VOLUME IV	-	REINFORCED CONCRETE DESIGN
VOLUME V	-	STRUCTURAL STEEL DESIGN
VOLUME VI	-	SPECIAL CONSIDERATIONS IN EXPLOSIVE FACILITY DESIGN

COMPUTER PROGRAM REPOSITORIES

FIGURE 1

VOLUME I

INTRODUCTION

- GENERAL INTRODUCTION – BACKGROUND, MANUAL SCOPE & FORMAT
- SAFETY FACTOR – SAFETY FACTOR APPLICATION
- EXPLOSION PROTECTION SYSTEM – DEFINITION OF COMPONENT (DONOR SYSTEM, ACCEPTOR SYSTEM, PROTECTIVE STRUCTURES, ETC.)
- DESIGN TOLERANCES – DEFINITION OF DESIGN PRESSURE RANGES, PROTECTION CATEGORIES HUMAN TOLERANCES, EQUIPMENT TOLERANCES, EXPLOSIVE SENSITIVITY

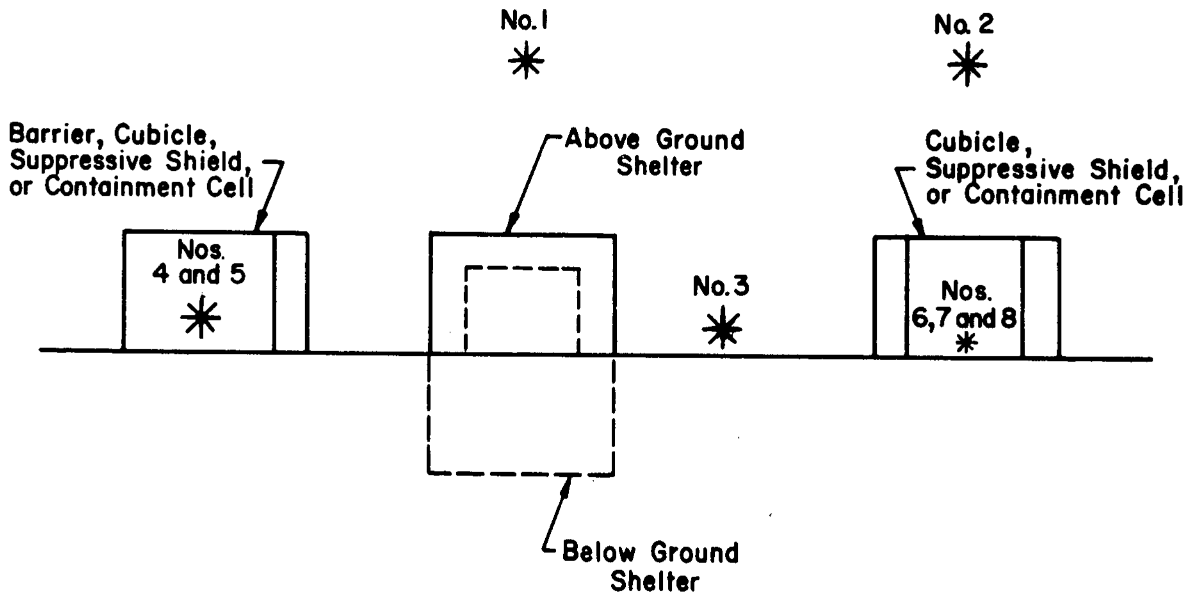
FIGURE 2

VOLUME II

BLAST, FRAGMENT AND SHOCK LOADS

- BLAST LOADS
  1. UNCONFINED EXPLOSIONS
  2. VENTED EXPLOSIONS
  3. CONFINED EXPLOSIONS
- FRAGMENTS
  1. **PRIMARY FRAGMENTS** - EXPLOSIVE CASING OR CONTAINERS
  2. **SECONDARY FRAGMENTS** - CAUSED BY EQUIPMENT BREAKUP
- SHOCK LOADS
  1. **GROUND MOTION** - AIR AND GROUND INDUCED
  2. **AIR BLAST MOTIONS** - SLIDING
  3. **SHOCK SPECTRA**

FIGURE 3



BLAST LOADING CATEGORIES		
Charge Confinement	**Category**	**Protective Structure**
Unconfined Explosions	1. Free Air Burst Loads 2. Air Burst Loads 3. Surface Burst Loads	Shelter
Vented Explosions	4. Exterior or Leakage Pressure Loads	Shelter
	5. Interior or High Pressure Loads	Barrier, Cubicle
Confined Explosions	6. Exterior or Leakage Pressure Loads	Shelter
	7. Interior or High Shock Pressure Loads	Cubicle, Suppressive Shield
	8. Gas Pressures	Partial or Total Containment

FIGURE 4

VOLUME III

PRINCIPLES OF DYNAMIC ANALYSIS

RESISTANCE-DEFLECTION FUNCTIONS	1. ULTIMATE RESISTANCE FOR ONE WAY SLABS AND BEAMS
	2. ULTIMATE RESISTANCE AND CRACK LINE PATTERNS FOR TWO-WAY SLABS AND FLAT SLABS
	3. ELASTIC, ELASTO-PLASTIC AND PLASTIC DEFLECTION CRITERIA
DYNAMICALLY EQUIVALENT SYSTEMS	1. LOAD, MASS AND RESISTANCE FACTORS
	2. LOAD-MASS FACTORS
	3. NATURAL PERIOD OF VIBRATION
DYNAMIC ANALYSIS	1. DESIGN CHART METHOD: 216 CHARTS FOR VARIOUS LOAD TYPES
	2. NUMERICAL INTERGATION PROCEDURES:
	A. AVERAGE ACCELERATION METHOD
	B. ACCELERATION IMPULSE EXTRAPOLATION METHOD
	C. TWO-DEGREE-OF-FREEDOM SYSTEM AND DAMPING
	3. IMPULSE METHOD

FIGURE 5

VOLUME IV

REINFORCED CONCRETE DESIGN

• DYNAMIC CAPACITY OF MATERIALS	1. INCREASE DYNAMIC INCREASE FACTORS 2. INCREASE MINIMUM YIELD STRENGTH 3. INCREASE SHEAR CAPACITY
• DESIGN FOR CLOSE-IN EFFECTS	1. LACED REINFORCED CONCRETE 2. SINGLE LEG STIRRUPS
• DESIGN FOR INTERMEDIATE RANGE	1. ONE AND TWO WAY PANELS 2. BEAM AND COLUMNS 3. FLAT SLAB CONSTRUCTION 4. TENSION MEMBRANE ACTION
• FOUNDATION DESIGN	1. OVERTURNING ANALYSIS 2. SOIL/STRUCTURE INTERACTION 3. FOUNDATION COMPONENT DESIGN
• BRITTLE MODE DESIGN	1. SPALLING 2. FRAGMENT PENETRATION
• CONSTRUCTION DETAILING	1. LACED REINFORCED CONCRETE 2. SINGLE LEG STIRRUPS 3. BEAM AND COLUMN 4. FLAT SLABS 5. FOUNDATIONS

FIGURE 6

VOLUME V
STRUCTURAL STEEL DESIGN

- **MECHANICAL PROPERTIES**
  1. STATIC STRESSES
  2. DYNAMIC STRESSES
- **DESIGN OF ELEMENTS**
  1. BEAMS AND PLATES
  2. COLUMNS AND BEAM COLUMNS
  3. BLAST DOORS
  4. COLD FORMED STEEL PANELS
- **PREL. FRAME ANALYSIS**
  1. SINGLE BAYS AND MULTI BAYS
  2. RIGID FRAMES AND BRACED FRAMES
  3. PRELIMINARY SIZING OF FRAME MEMBERS
- **CONSTRUCTION**
  1. FRAMING REQUIREMENTS
  2. CONNECTION DETAILS
- **FRACTURE DESIGN**
  1. CLOSE-IN EFFECTS
  2. STEEL CONTAINMENT STRUCTURES

FIGURE 7

VOLUME VI
SPECIAL CONSIDERATIONS IN EXPLOSIVE FACILITY DESIGN

. MASONRY DESIGN	1. DESIGN PROCEDURES AND CONSTRUCTION METHOD
. PRECAST CONCRETE DESIGN	1. DESIGN PROCEDURES AND CONSTRUCTION METHOD
. SPECIAL PROVISIONS FOR PRE-ENGINEERED BUILDINGS	1. DESIGN LOADS AND REQUIREMENTS 2. TYPICAL SPECIFICATIONS
. SUPPRESSIVE SHIELDING	1. OUTLINE OF DATA CONTAINED IN "SUPPRESSIVE SHIELDS - STRUCTURAL DESIGN AND ANALYSIS HANDBOOK" (HNDM 1110-1-2)
. BLAST RESISTANT WINDOWS	1. DESIGN PROCEDURES FOR GLAZING AND WINDOW FRAMES SUBJECTED TO BLAST LOADS
. DESIGN LOADS FOR UNDERGROUND STRUCTURES	1. OUTLINE OF DATA CONTAINED IN "FUNDAMENTALS OF PROTECTIVE DESIGN FOR CONVENTIONAL WEAPONS"
. EARTH-COVERED ARCH-TYPE MAGAZINES	1. INVESTIGATION, DESIGN, CONSTRUCTION AND STANDARD DRAWINGS FOR MAGAZINES
. SHOCK ISOLATION SYSTEM	1. METHOD AND PROCEDURES FOR DESIGN OF SHOCK ISOLATION SYSTEMS ARE PRESENTED FOR BOTH PERSONNEL AND EQUIPMENT
. BLAST VALVES	1. DISCUSS VARIOUS TYPE OF BLAST VALVES AND ASSOCIATED EQUIPMENT

FIGURE 8

PEACEKEEPER QUANTITY-DISTANCE VERIFICATION PROGRAM
PART I

ANALYTICAL AND EXPERIMENTAL PROGRAM FOR QUANTITY-DISTANCE EVALUATION OF PEACEKEEPER MISSILES IN MINUTEMAN SILOS

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ABSTRACT

An analytical and experimental program was conducted for the purpose of establishing quantity-distance (Q-D) criteria associated with an explosion of a Peacekeeper missile in an operational Minuteman silo. The experimental program consisted of the detonation of high explosive charges within 1/10- and 1/4-scale models of a Minuteman silo , and a 1000-lb TNT calibration test. Measurements were made of airblast overpressures and fragment dispersion characteristics. The airblast measurements were highly successful with all of the pressure channels recording and providing good data. Color-coded structural fragments were evaluated in terms of dimension, weight, number, and location for the purpose of the Q-D analysis.

INTRODUCTION

This paper is Part I of a two-part summary of the Peacekeeper Quantity-Distance Verification Program briefed at the 21st DOD Explosive Safety Seminar. Part II is a description of the technical and analytical investigations performed to support the program (Reference 1). Additional information is contained in the final report of the Q-D study (Reference 2).

BACKGROUND

Upon the decision of President Reagan to base 100 Peacekeeper missiles in the Minuteman 319th and 400th Strategic Missile Squadrons of Wing V at F. E. Warren Air Force Base, Wyoming, it became necessary to consider the implications of an accidental explosion of a Peacekeeper missile in an underground Minuteman silo. For planning purposes, the Department of the Air Force Inspector General established a Q-D estimate of 1750 feet from inhabited buildings (IBs). As a result, the Peacekeeper Program Management Directive (PMD) No. 0075 (13)/64312F/11215, section 3a(1)(b)(r), dated 14 September 1983, directs Air Force Systems Command (AFSC) to "Verify through analysis and testing, the Q-D criteria established by HQ USAF/IG for planning purposes for Peacekeeper in Minuteman silos."

The Ballistic Missile Office (BMO) System Safety Division (AWS) developed a Quantity-Distance Program Plan which established a test and analysis approach to confirm the safety separation distances for IB based upon requirements specified in Air Force Regulation (AFR) 127-100. These requirements are the determination of the ground range for essentially a peak overpressure level of 1 psi in comparison with the ground range for a hazard fragment density of one fragment per 600 sq ft having an impact energy of 58 ft-lb or greater as associated with an in-silo explosion of a full-scale missile or equivalent TNT charge. A net explosive weight (NEW) of 202,000 lb TNT equivalence for the Peacekeeper missile was used in the test and analysis program as a conservative upper bound which assumes full order sympathetic detonation of progressive stages following the initiation of Stage III. This NEW had been derived by multiplying the weight of all DOT Class 1.3 propellants (Stages I and II) by a factor of 1.20 and DOT Class 1.1 (Stage III) by 1.25, and taking a total sum.

OBJECTIVES

The principle objective of the Quantity-Distance Verification Program was to verify the adequacy of 1750 ft IB as the Q-D for an explosion associated with a Peacekeeper missile within the Minuteman silo. This objective would be accomplished in the following two-fold manner:

a) **Test Program.** The objectives of the test program were:

- To provide experimental data as a basis for the verification of a Q-D value of 1750 ft.
- To evaluate the applicability of subscale testing toward full-scale testing events.
- To obtain airblast measurements for scale model tests.
- To obtain debris/ejecta distribution data with respect to distance due to an explosion within a scale model silo.

b) **Analytical Program.** The objectives of the analysis program were:

- To develop analytical models to permit predictions of airblast and debris/ejecta phenomenology associated with scale model tests.
- To establish procedures for scaling test data.
- To evaluate scale model test data for the purpose of the verification of Q-D criteria for a full-scale event.
- To establish modified Q-D in case 1750 ft proves inadequate.

PROGRAM DEFINITION

Considerations were directed toward establishing a minimum test program adequate for verifying the Q-D criteria. The tests are briefly outlined as follows:

a) Two 1/10-scale tests of steel structures scaled to volume and mass of a Minuteman Wing V silo; explosive charge consisting of 202 lb of TNT; blast measurements only.

b) One 1/4-scale test of reinforced concrete structure with detailed representation of a Minuteman Wing V silo; explosive charge consisting of 3156 lb of TNT; blast and debris/ejecta measurements.

c) One 1000-lb TNT surface tangent sphere as a calibration shot; blast measurements only.

In the analysis program, attention was focused principally on three aspects; airblast phenomena, structural fragmentation characteristics, and debris scaling procedures. The airblast analytical model was calibrated by means of a calculation for a rigid silo configuration similar to an analysis by S-Cubed of Albuquerque for DNA, and an analytical determination of the blast effects associated with a selected previous experiment for correlation with empirical results. Test predictions were developed for the airblast and fragment distributions associated with the scale model tests. An evaluation was performed of the Q-D corresponding to a full-scale operational event.

PROGRAM MANAGEMENT

The Peacekeeper Quantity-Distance Verification Program was sponsored by the Ballistic Missile Office (BMO/AWS) of the Air Force Systems Command, Norton Air Force Base, California. Technical assistance was furnished by two divisions of the TRW Defense Systems Group, namely, the Ballistic Missile Division, San Bernardino, California, and Systems Engineering and Development Division, Space Park, Redondo Beach, California.

The Test Program conductor and integrating contractor was the Structures Laboratory of the U.S. Army Engineers, Waterways Experiment Station (WES), Structural Mechanics Division (SMD), Vicksburg, Mississippi. Technical and field support was furnished to SMD by WES Explosion Effects Division (EED), and WES Geomechanics Division (GD), Vicksburg, Mississippi, Field Command Defense Nuclear Agency (DNA), Kirtland AFB, New Mexico, White Sands Missile Range, New Mexico, and Denver Research Institute, Denver, Colorado.

The Analytical Program was performed by TRW Defense Systems Group, Redondo Beach, California.

Figure 1 depicts the management structure of the Peacekeeper Quantity-Distance Verification Program.

TEST DESCRIPTION

The Q-D tests (QDTs) were conducted at the Permanent High Explosive Test Site (PHETS), White Sands Missile Range, New Mexico. Although alternative sites were considered, the PHETS North Park area was selected due to its relative flatness and area of cleared real estate. It also possessed a water table of approximately 130 ft in depth so that interference with the test beds was of no concern.

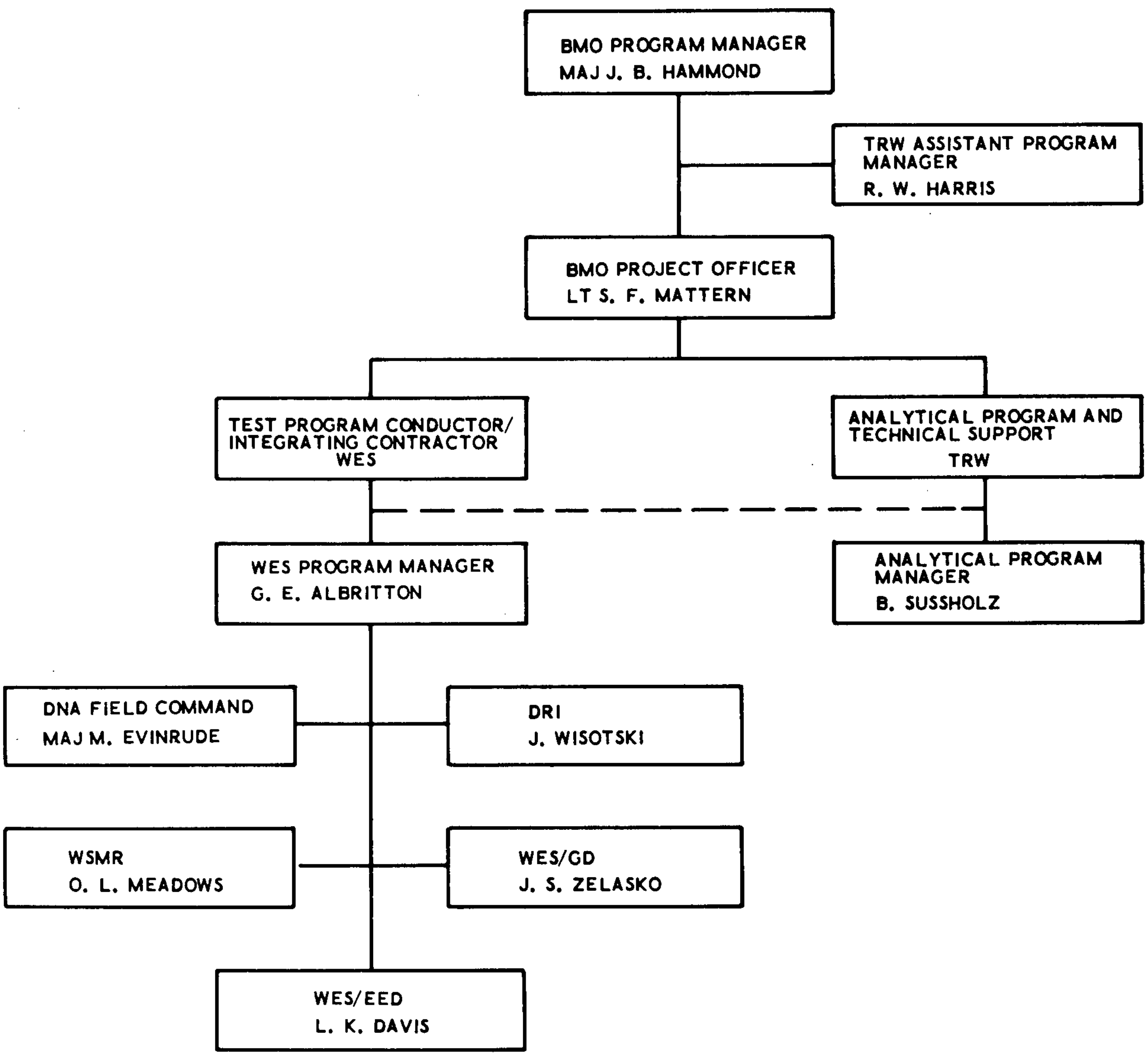

Figure 1. Management Structure

Test Articles

One-quarter scale construction drawings were prepared and furnished to WES/SMD by TRW for the construction of the 1/4-scale test structure. Additional schematic drawings were furnished for the fabrication of two 1/10-scale steel structures to be utilized in QDT-1 and -2. All test articles were constructed at the WES/SMD lab facilities at Vicksburg, Mississippi and later transported to White Sands Missile Range for use in the QDT tests.

One-Tenth-Scale Structure. The two 1/10-scale structures were a volumetric representation of the Minuteman silo, constructed of steel plate with an overall length of 8 ft 2-3/4 in. In addition, the volume and configuration of the launcher equipment room (LER) was modeled so the airblast exiting the structure would be correctly simulated. Each structure consisted of a launch tube (LT), LER, and closure (Figure 2). Two

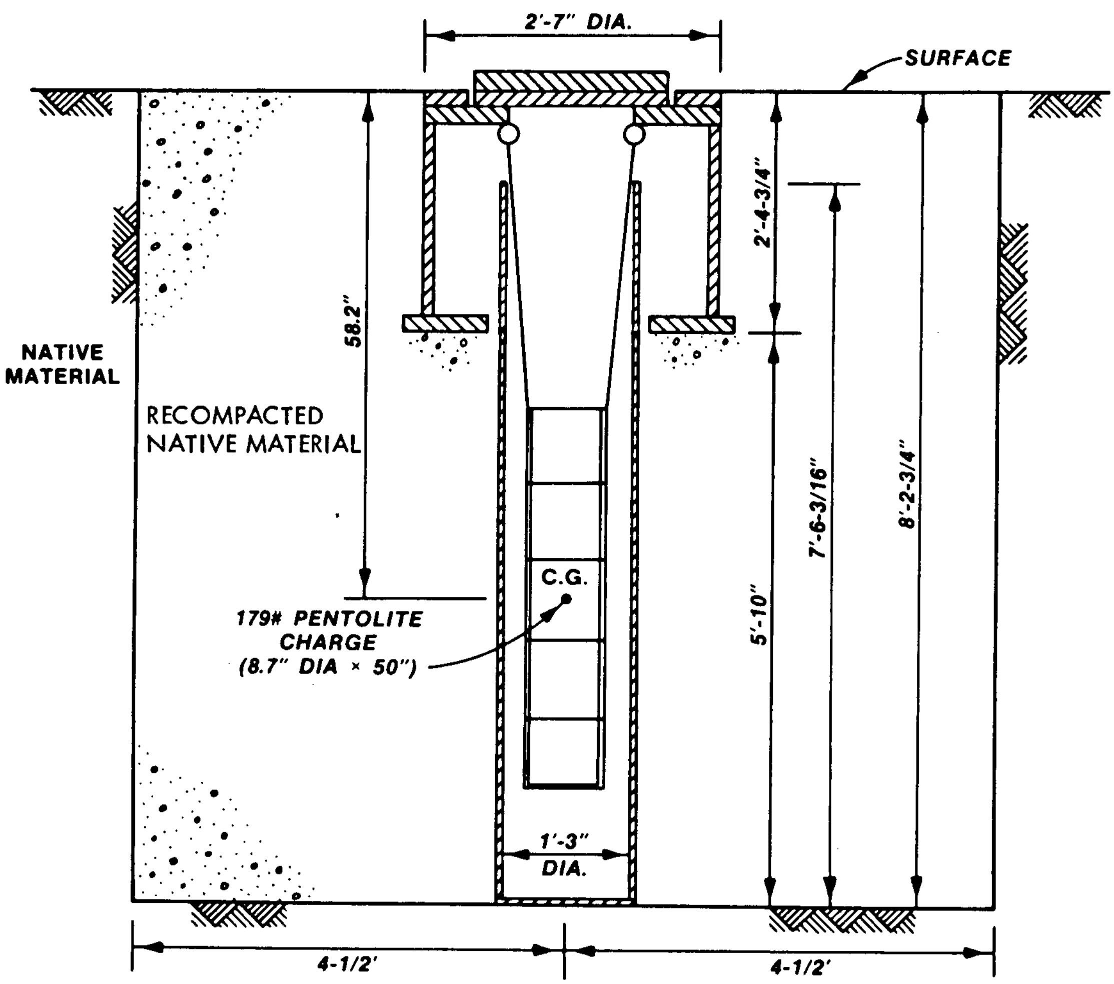

Figure 2. One-Tenth Scale Test Article and Test Bed Configuration

complete 1/10-scale tests were performed to evaluate reproducibility and to provide a statistical data base for scaling evaluation of airblast results of the 1/4-scale test.

One-Quarter-Scale Structure. The 1/4-scale Minuteman model consisted of three structures: the LT, LER, and closure (Figure 3). The LT was an axisymmetric reinforced concrete structure having an internal diameter of 3 ft and an overall length of 16 ft 6 in. The addition of an inner steel liner extended the overall length to 18 ft 9 in. The LER was an asymmetric reinforced concrete structure with an inner steel liner having an internal diameter of 6 ft 3 in. and an overall length of 8 ft 1-1/2 in. The asymmetry was due to the personnel access hatch (PAH) included in the LER. The closure was constructed from reinforced concrete in a pie pan container with a depth of 10.5 in. A 2-1/2-in. concrete layer representing the upgrade to Wing V was placed on top of the closure and LER. It should be noted that all QDT testing was accomplished with the closure in place.

To aid in the identification of fragments, the test article was divided into regions shown in Figure 4. Each region, during construction, was color-coded by adding concrete dye to the concrete mix. This color-coding allowed for the determination of the regions of the structure that represented the source of the debris collected at various locations after the test.

Explosive Charges. The explosive charges selected for the tests were Pentolite 50/50 (energy density 13% greater than TNT) due to a higher reliability than TNT. The specified 179-lb charges for the 1/10-scale silo tests were cast in a single integral cylinder made from 16-gage steel plate to simulate the canister of the Peacekeeper missile. The charges had a well in the center of the top of the cylinder to place the detonator. Charge detonation was 0.4 ft below the top, which corresponded to the scaled depth of the center of gravity (cg) of Stage III. Each charge was 50 in. in length and 8.7 in. in diameter. For each 1/10-scale test, the charge was suspended by a harness and cables in the LT with the center of gravity of the charge was 58.2 in. below the ground surface. The charge cg, depicted in Figure 2, represents the cg depth for the Peacekeeper missile propellants.

The specified 2,790-lb charge for the 1/4-scale test was cast in a single integral cylinder made from 1/8-inch thick steel plate. The charge had a well point in the center top of the container in which to place a detonator for firing. Charge detonation was 1 ft below the top, and charge dimensions were 125 in. in length and 21.8 in. in diameter. The charge was also suspended by a harness and cables with its center of gravity at a distance of 159 in. below the ground surface (Figure 5).

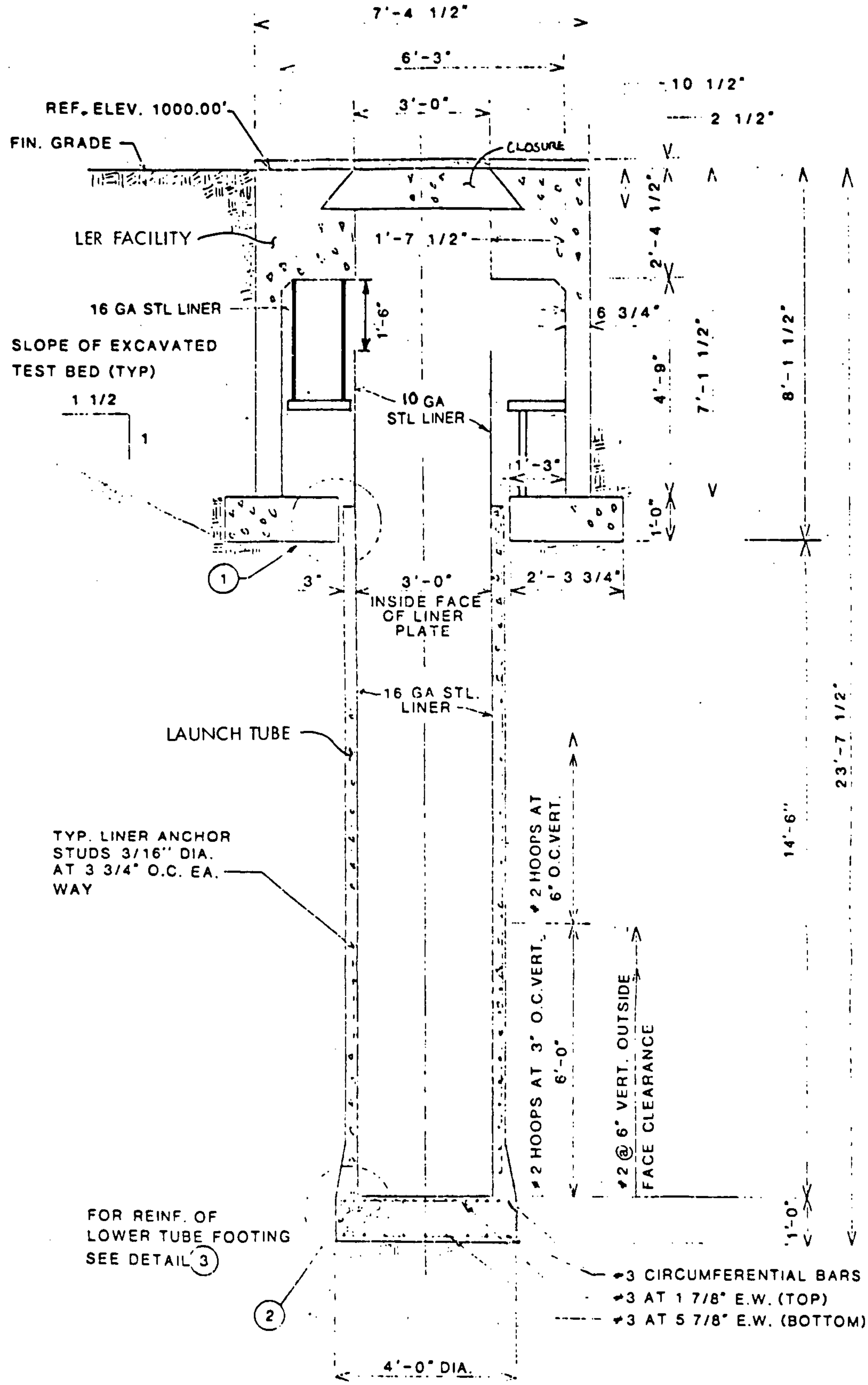

Figure 3. One-Quarter-Scale Structure

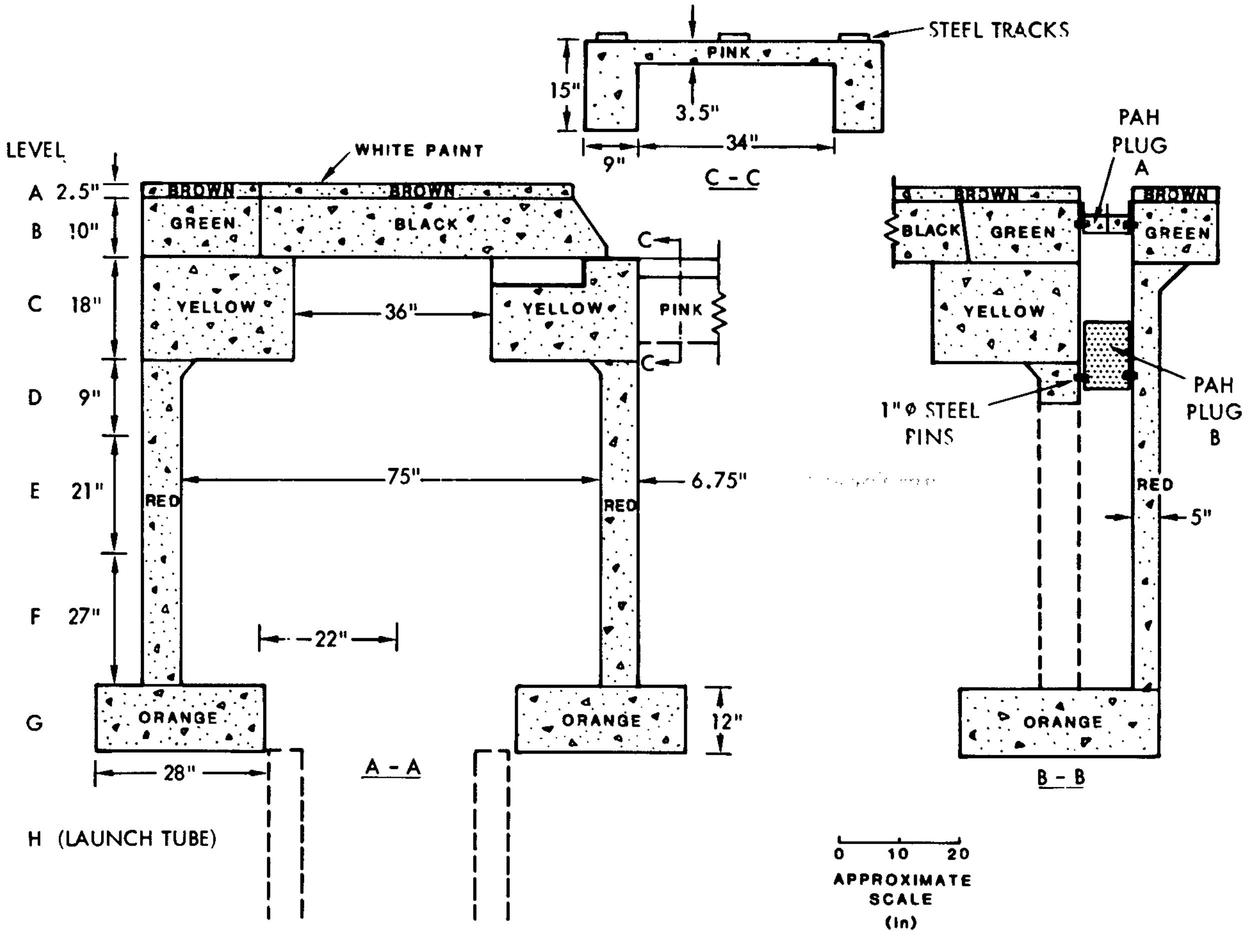

Figure 4. One-Quarter-Scale LER Cross-Sections

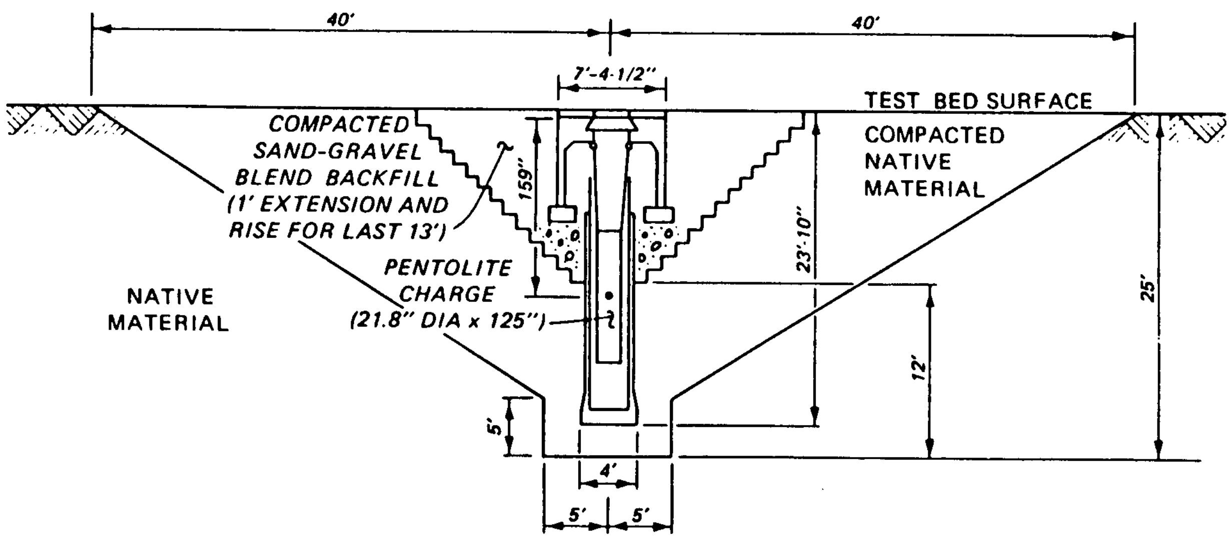

Figure 5. One-Quarter-Scale Test Bed Layout

Site Layout. As noted previously, QDT-1, -2, and -3 were conducted at the PHETS, North Park area of White Sands Missile Range (Figure 6). Site preparation was accomplished as follows:

a) **Field Preparation.** The layout of the two 1/10-scale tests consisted of utilizing the same ground zero (GZ) with two 350-ft radial lines cleared 90° apart, 100 ft in width (Figure 6). An 8-ft 2-3/4-in. hole, 9-ft sq was excavated at the GZ and the structure lowered into place. The backfill (native material) was compacted in 6-in. lifts to achieve the desired density. The QDT-1 site was reconstituted after the test in preparation for QDT-2.

   The instrumentation layout for the 1/4-scale test depicted in Figure 7 shows the three radials which were cleared 120° apart out to 1750 ft. The radials were cleared 100 ft in width out to 1000 ft and 50 ft in width from 1000 ft to 1750 ft. Circumferential radials, 25 ft in width, were also cleared at the 400-and 1000-ft range, 30° on each side of the 0, 120, and 240° radials. The test bed excavation, indicated in Figure 5, included an open pit which was 80 ft by 80 ft wide by 20 ft deep, with the sides having a one-to-one slope. The final excavation was a 10 x 10 x 5 ft deep inner bed, making a total depth of excavation of 25 ft. The LT was lowered into place and native material was used to backfill in 2-ft lifts up to 12 ft. Simulated Wing V backfill was then utilized and compacted to the required density up to the 15-ft 6-in. level. Here the LT liner extension was welded into place and the LER lowered into position with the PAH aligned to the northeast (120° radial). Backfill of simulated Wing V material continued to the 21-ft 6-in. level where the track footing for the closure was installed and the three tracks grouted into place. Backfill to ground surface was then completed.

b) **Backfill Characteristics.** QDT-1 and -2 utilized the native materials excavated from the site for backfill, whereas QDT-3 was backfilled initially with native materials and then finally with material that simulated that of Wing V native soils of Wyoming and Nebraska. The WES/Geomechanics Division analyzed core drillings of each of the 100 Wing V sites of interest and provided a gradation curve which was used to blend materials to acceptable limits to match that of Wing V. Once the backfill material had been blended and was on site, bag samples were obtained from every 100 cu yd delivered, for the purpose of several soil properties tests including uniaxial strain tests up to 1 kbar as well as triaxial tests. Figure 8 shows the Q-D simulated backfill within the acceptable limits established by the gradation specification curves provided by WES/GD. In addition, a mixture of 3/4-in. particles up to 12 in. were added to the blended material and represented 1/2% of the total mass of simulated material.

c) **Airblast Instrumentation.** The airblast instrumentation for each 1/10-scale test consisted of Kulite sensors along the centers of two radial lines extending from GZ at 90° separation. There were 15 gages on each radial (total of 60 gages for QDT-1 and -2) extending over a range of 17 ft out to 530 ft from ground zero (Table 1).

   Test QDT-3 and the calibration shot each had 45 channels of Kulite airblast gages located along the centerlines of three radials extending from GZ at 120° separation. There were 15 gages on each radial extending over ranges of 42 ft out to 1320 ft (Table 2).

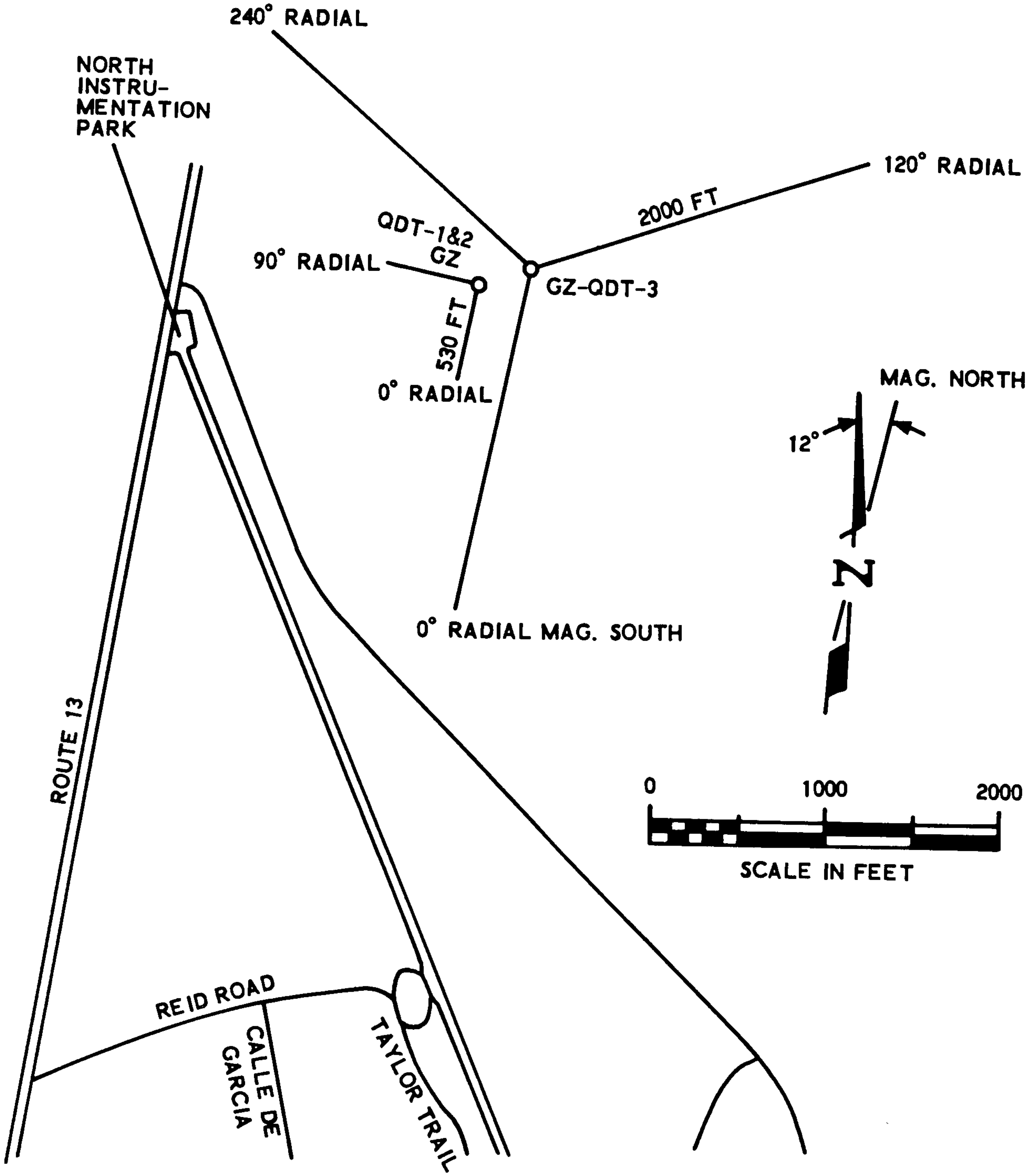

Figure 6. Test Site Layout for QDT-1, QDT-2, and QDT-3

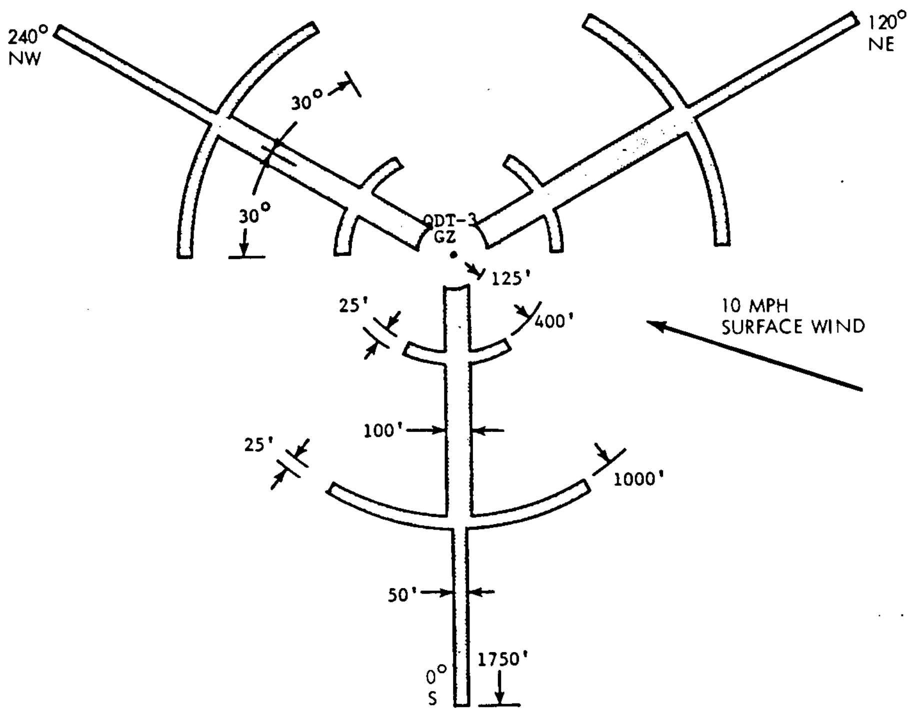

Figure 7. Locations of Areas Requiring Brush Clearing for Airblast Gages and Ejecta Surveys

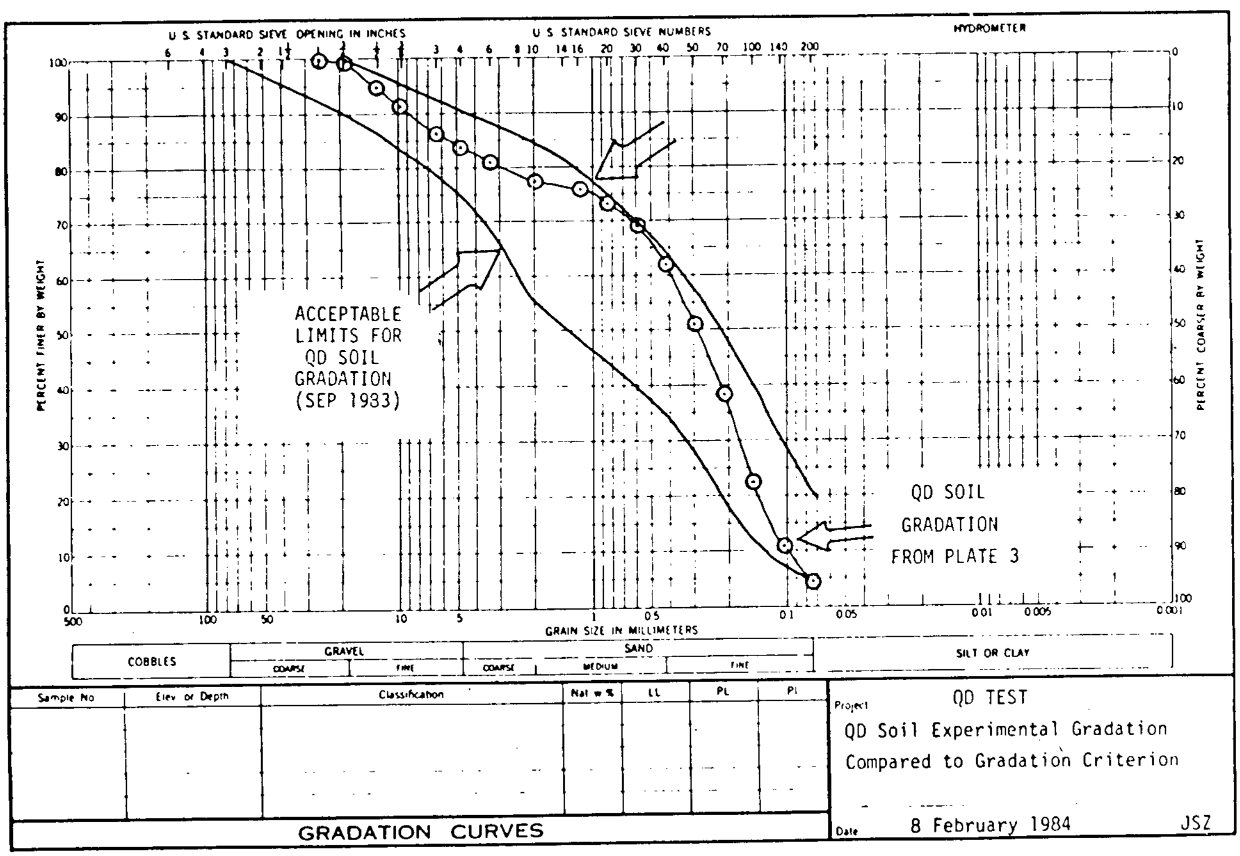

Figure 8. Comparison of Q-D Soil (70:30 Mix) Gradation With Criterion Band

Table 1. Airblast Instrumentation Locations for 1/10-Scale Tests on Each Radial

Gage No.	Distance from GZ (ft)
BP1	17
BP2	30
BP3	44
BP4	52
BP5	65
BP6	82
BP7	100
BP8	130
BP9	160
BP10	200
BP11	245
BP12	295
BP13	350
BP14	430
BP15	530

Table 2. Airblast Instrumentation Locations for 1/4-Scale Test on Each Radial

Gage No.	Distance from GZ (ft)
BP1	42
BP2	78
BP3	110
BP4	130
BP5	160
BP6	200
BP7	250
BP8	325
BP9	400
BP10	500
BP11	610
BP12	740
BP13	880
BP14	1080
BP15	1320

d) **Passive Measurements.** The passive measurements included the following activities:

1) **Seeded Ejecta.** In order to determine the origin of natural missiles impacting beyond the continuous ejecta region, the backfill and in-situ soil in the expected crater area was seeded with artificial missiles along the northeast radial. Two types of artificial missiles were used. One-inch cubes of colored plastic, each stamped with an identification number, were placed in vertical sand columns. Aluminum cubes measuring 1, 2, 4, and 8 in. on a side, each containing identification numbers, were buried at 15 locations along the northeast radial, before and during placement of backfill soil around the silo. Each cluster contained sixteen 1-in., eight 2-in., four 4-in., and two 8-in. cubes.

2) **Plastic Witness Sheets.** Plastic sheets measuring approximately 10 x 10 ft in area (100 sq ft) were installed on the ground surface at selected locations in all ejecta/debris survey areas for use in determining missile impact densities. They were spaced in groups of three at intervals of 125 ft out to a range of 1000 ft, and then placed in pairs at intervals of 250 ft out to a range of 1750 ft. In addition, collector sheets were located at 10° intervals around each survey ring.

3) **Ground Survey.** Immediately after the test, a survey was made of ejecta/debris fragments located on witness sheets, lying within the three survey sectors and two circumferential rings to record location, color, weight, and number. The search for seeded missiles was concentrated in the survey sectors and circumferential rings. The survey of structural debris was limited to fragments having a maximum dimension of at least 1/2 in.

e) **Photography.** Video and Hulcher film photography were obtained for the two 1/10-scale tests, whereas QDT-3 had both documentary photography and high-speed motion picture photography. The camera coverage for QDT-3 included the initial rise and growth of the crater mound, early trajectories of material thrown out by the detonation and impact of ejecta/debris pieces beyond the continuous ejecta field. Table 3 describes the camera coverage and locations. Figure 9 depicts camera stations and field of view for each camera.

Table 3. Camera Requirements for Peacekeeper One-Quarter-Scale Test

No.	WSMR Camera Number	Purpose	Format	FOV (HXW)	Frame Rate	Reso-lution	Exposure (ms)	Run Time (sec)	Aim Point Range X Elevation
1	3714	Initial silo breakup (ambient)	Fastax II 16mm	25' x 33'	6000	2"	0.1 VNF	0.6	0 x 8'
2	3715	Initial ejecta parameters	Photosonic 70mm	375' x 375'	64.0	4"	0.1 VNF	30	0 x 150'
3	3716	Initial ejecta parameters	Photosonic 70mm	750' x 750'	60.0	8"	0.1 VNF	30	0 x 300'
4	3717	Ejecta impact parameters	Photosonic 70mm	180' x 180'	60.5	2"	0.1 VNF	15	80'S x 80'
5	3718	Ejecta impact parameters	Photosonic 70mm	180' x 180'	64.0	2"	0.1 VNF	15	80'NE x 80'
6	3719	Ejecta impact parameters	Photosonic 70mm	180' x 180'	63.9	2"	0.1 VNF	15	250'S x 80'
7	3720	Ejecta impact parameters	Photosonic 70mm	180' x 180'	62.3	2"	0.1 VNF	15	420'S x 80'
8	3721	Initial silo	Hycam 16mm	25' x 33'	6000	2"	0.05 IR EKTA	0.6	0 x 8'
9	--	Ejecta impact along 0° radial	Locam 16mm	150' x 200'	48	-	0.1 VNF	45	SGZ
10	3722	Ejecta impact parameters	Photosonic 70mm	180' x 180'	63.0	2"	0.1 VNF	15	590'S x 80'
11	3723	Ejecta impact parameters	Photosonic 70mm	180' x 180'	61.0	2"	0.1 VNF	15	760'S x 80'
12	--	Ejecta impact along 120° radial	Locam 16mm	150' x 200'	48	-	0.1 VNF	45	SGZ
13	3725	Ejecta impact parameters	Photosonic 70mm	180' x 180'	63.4	2"	0.1 VNF	15	250'NE x 80'

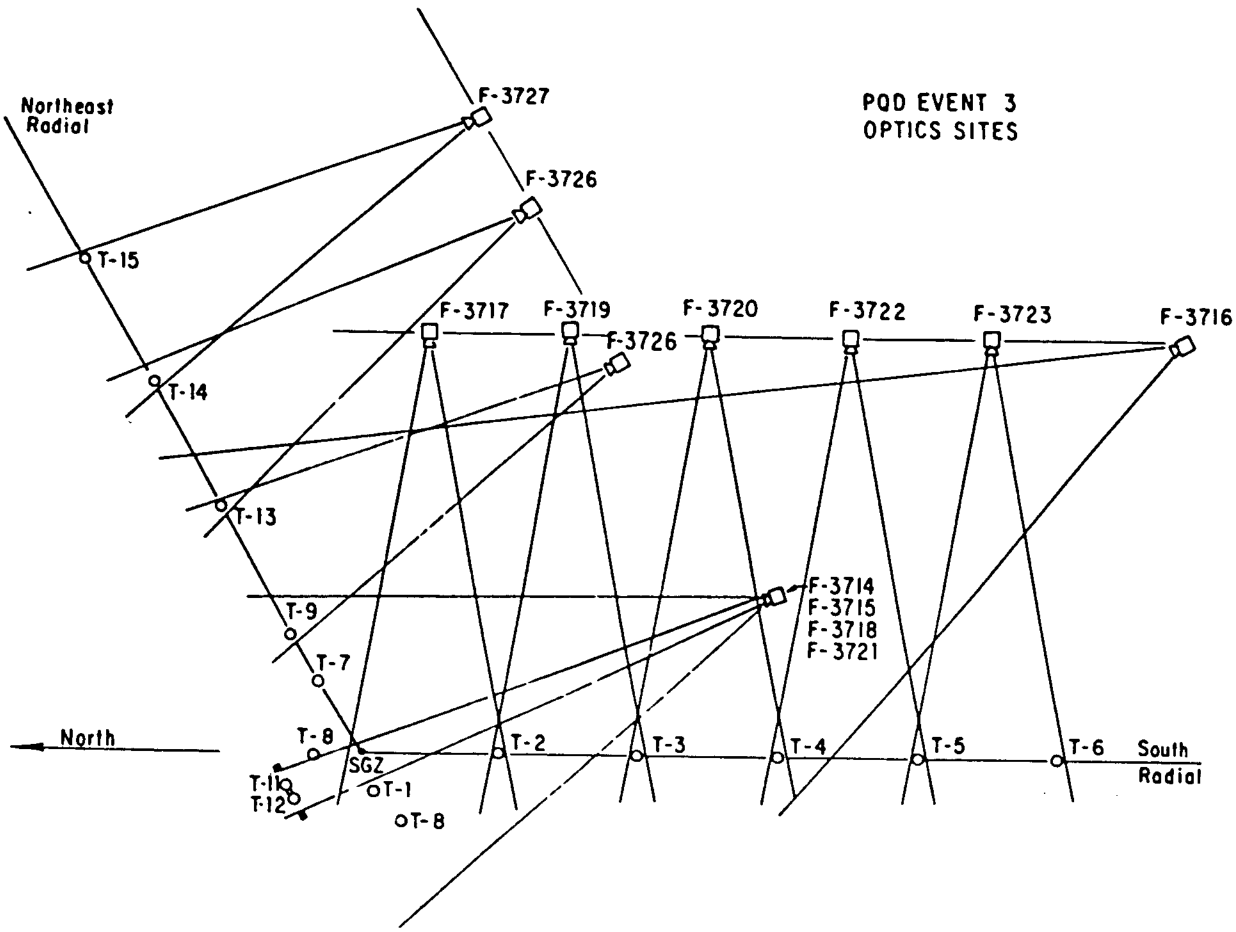

Figure 9. Camera Locations and Coverages for Debris/Ejecta Photography

TEST RESULTS

The schedule for the Q-D test program was as follows:

Test	Date
QDT-1	26 January 1984
QDT-2	01 February 1984
QDT-3	29 March 1984
Calibration	07 March 1984

Airblast Measurements

The airblast measurements were highly successful. All of the 150 pressure channels recorded and provided good data. The original test program incorporated only two 1/10-scale tests and the 1/4-scale test. During the course of the test events, it became apparent that the resulting peak overpressure levels were considerably lower than had

originally been anticipated. Therefore, it was considered advisable to conduct a calibration shot in order to evaluate the reliability of the sensors and recording equipment as a total integrated system.

One-Tenth Scale Tests

The actual explosive charges for the 1/10-scale QDT-1 and -2 tests consisted of 172 lb of Pentolite 50/50. A brief summary is given in Table 4 of the peak pressure, positive duration, and arrival time data as a function of range.

The surface wind velocities as measured in close proximity to the instrumentation trailer were essentially zero at shot time for both tests, with measurements of meteorological conditions indicating wind velocities increasing with altitude up to the order of several miles per hour at heights of about 200 ft for QDT-1 and 1000 ft for QDT-2.

The average crater dimensions for QDT-1 were 12.9 ft radius and 8.3 ft deep, whereas the corresponding dimensions for QDT-2 were 12.3 ft radius and 7.6 ft deep. None of the QDT-1 test structures were observed within the apparent crater. However, a piece of the QDT-2 launch tube remained in the crater after the explosion.

One-Quarter Scale Test

The actual explosive charge for the 1/4-scale QDT-3 test consisted of 2685 lb of Pentolite 50/50. A summary of the peak pressure, positive duration, and arrival time as a function of range is shown in Table 5. Surface wind velocity as measured near the instrumentation trailer at shot time was 10 mph in a direction of 110^{o} azimuth relative to True North. The average crater dimensions were 23.7 ft radius and 10.0 ft depth. Upon inspecting the crater, it was apparent that none of the structure remained in the test bed. It appeared that complete detonation of the explosive charge had occurred.

Calibration Shot

The QDT-3 calibration shot consisted of a tangent sphere of 1017 lb of TNT located at the GZ of the QDT-3 test bed which had been reconstituted prior to the calibration test. A summary of peak overpressure, positive duration, and arrival time data is presented in Table 6. Wind velocity at ground surface was approximately 1 mph at zero time.

Table 4. QDT-1 and QDT-2 Airblast Test Results

Range (feet)	QDT-1 Data						QDT-2 Data					
	S Radial			W Radial			S Radial			W Radial		
	Peak Pressure (psi)	Positive Duration (msec)	Arrival Time (msec)	Peak Pressure (psi)	Positive Duration (msec)	Arrival Time (msec)	Peak Pressure (psi)	Positive Duration (msec)	Arrival Time (msec)	Peak Pressure (psi)	Positive Duration (msec)	Arrival Time (msec)
17	11.4	3.88	10.1	11.9	4.65	9.3	11.2	3.61	9.20	8.39	6.49	10.7
30	5.37	6.20	19.2	4.96	7.75	20.1	5.70	7.76	18.6	5.24	7.36	19.6
44	3.00	7.75	30.1	3.10	8.53	27.0	3.39	8.44	30.6	3.28	8.50	31.2
52	2.33	9.30	36.7	2.48	9.30	37.0	2.60	9.10	37.4	2.88	8.96	37.9
65	1.49	9.80	48.4	1.88	10.1	47.8	1.83	9.40	47.2	2.27	9.44	48.9
82	1.04	10.4	62.6	1.04	10.4	61.6	1.22	9.70	61.5	1.15	10.0	63.4
100	1.12	10.8	77.0	0.88	10.8	77.8	1.33	10.4	76.8	0.86	10.6	79.1
130	0.59	11.6	103	0.61	11.6	104	0.62	11.2	103	0.65	11.5	106
160	0.49	12.4	129	0.48	12.4	131	0.52	11.7	129	0.51	12.2	132
200	0.39	13.2	165	0.40	13.2	166	0.38	12.6	164	0.57	13.0	169
245	0.29	13.6	205	0.30	14.0	206	0.33	12.8	203	0.35	13.5	210
295	0.26	14.0	249	0.20	14.7	251	0.25	13.6	248	0.22	14.8	255
350	0.20	14.3	299	0.15	14.0	301	0.21	14.3	296	0.17	14.5	305
430	0.20	14.7	371	0.12	15.5	373	0.17	14.7	366	0.13	14.4	379
530	0.13	15.5	460	0.09	16.3	463	0.12	15.5	455	0.09	16.0	470

Table 5. QDT-3 Airblast Test Results

Range (feet)	S Radial			NE Radial			NW Radial		
	Peak Pressure (psi)	Positive Duration (msec)	Arrival Time (msec)	Peak Pressure (psi)	Positive Duration (msec)	Arrival Time (msec)	Peak Pressure (psi)	Positive Duration (msec)	Arrival Time (msec)
42	13.8	11.8	20	13.1	13.8	22	11.4	11.8	24
78	6.68	15.7	45	5.17	15.7	49	6.25	15.7	49
110	3.53	19.7	70	3.32	21.6	74	4.07	20.7	66
130	3.06	21.6	85	2.78	23.6	91	2.82	21.6	93
160	2.02	23.6	112	1.83	24.6	116	1.96	22.6	116
200	1.14	25.6	145	1.16	25.6	149	1.71	23.6	149
250	1.21	27.8	189	0.94	27.6	193	1.09	24.6	191
325	0.87	31.5	258	0.66	29.5	260	0.64	25.6	258
400	0.57	33.5	324	0.46	31.5	324	0.60	27.6	324
500	0.41	35.4	414	0.45	33.5	416	0.50	29.5	416
610	0.28	37.4	514	0.27	35.4	514	0.28	31.5	510
740	0.23	39.4	631	0.20	36.4	630	0.33	32.5	626
880	0.17	41.3	758	0.16	37.4	756	0.26	34.4	741
1080	0.12	43.3	941	0.12	38.4	935	0.21	36.4	918
1320	0.08	45.3	1158	0.11	39.4	1141	0.19	37.4	1143

Structural Debris

Table 7 presents a summary of the number of concrete fragments located within the South, Northeast, and Northwest radials from ranges of 125 to 1000 ft. No fragments were observed within the respective radials for ranges of 1000 to 1750 ft.

It was originally assumed that the proposed distribution of debris collector pads of 10 x 10 ft dimension would yield sufficient data for analysis of the QDT-3 results and scaling to a full-scale event. However, immediately following collection of the witness sheet data, it became apparent that the observed total of 853 fragments would be inadequate to afford a reasonable data base for the statistical analysis. It was estimated that this number of fragments represented perhaps less than 1% of the total number expected for an event of this nature. It would appear that application of small sample statistics would have been required which was considered unsatisfactory for the purpose intended.

Table 6. Calibration Shot Airblast Test Results

Range (feet)	S Radial			NE Radial			NW Radial		
	Peak Pressure (psi)	Positive Duration (msec)	Arrival Time (msec)	Peak Pressure (psi)	Positive Duration (msec)	Arrival Time (msec)	Peak Pressure (psi)	Positive Duration (msec)	Arrival Time (msec)
42	89.0	16.7	5.9	91	----	----	78	15.7	7.9
78	17.3	18.7	25.9	16	18.7	25.9	16.5	18.7	25.9
110	8.5	23.6	47.9	8	25.6	47.9	8.8	23.6	47.9
130	6.4	27.6	62	6.3	29.5	62	6.2	28.5	63.9
160	4.3	30.5	85.9	3.7	31.5	85.9	3.8	30.5	85.9
200	2.5	32.5	120	2.7	33.5	120	3.6	33.5	120
250	2.8	36.4	162	2.1	36.4	162	2.14	36.4	160
325	1.8	41.3	226	1.34	40.4	226	1.05	40.4	224
400	1.09	44.3	294	0.93	43.3	290	1.05	42.3	290
500	0.78	47.2	382	0.75	45.3	380	0.71	44.3	378
610	0.62	49.2	480	0.54	48.2	476	0.55	48.2	476
740	0.46	51.2	598	0.40	50.2	592	0.47	51.2	592
880	0.38	53.1	724	0.33	52.2	718	0.37	53.1	718
1080	0.285	55.1	904	0.26	55.1	898	0.26	56.1	898
1320	0.195	57.1	1122	0.27	57.1	1114	0.21	58.1	1114

A second debris collection effort was initiated covering specific regions of 50 x 57.5 ft dimension (area of 2875 sq ft) located on the right of the centerline of the cleared areas of the three radials. An additional group of 424 fragments were recorded by this means. At this stage, the total of 1277 fragments was still considered inadequate. As a third collection effort, the entire left segments of the three radials were covered, wherever possible, which yielded another increment of 3455 fragments. The total of 4732 fragments was then considered to be a reasonable statistical sample.

The total collection area covered in the process was about 190,000 sq ft, which represented 6.2% of the circumferential area between radii of 125 and 1000 ft. To a first order extent, assuming azimuthal symmetry, it is estimated that a total of 4732/0.062, or 76,300 fragments, were projected within the ranges covered by the debris collection.

A considerable data reduction effort was instituted toward determining a set of debris characteristics in relation dimensions, weight, and color for a large fraction of the fragments collected.

Table 7. QDT-3 Debris Data Summary

Range (ft)	Radial Area 3 (10 ft x 10 ft) S	NE	NW
125	135	122	126*
250	67	49	188
375	18	15	60
500	11	2	42
625	0	1	7
750	0	0	4
875	0	0	2
1000	2	0	2
Total	233	189	431

Number of Fragments 4732

Area $A_o = 190{,}900\ ft^2$

Total Area
$$A_T = \pi(1000^2 - 125^2) = 3{,}090{,}000\ ft$$
$$\frac{A_o}{A_T} = 6.2\%$$

Total Number of Fragments
$$N_T = \frac{4732}{0.062} = 76{,}300$$

*Data for two witness sheets

Range (ft)	S Radial		NE Radial		NW Radial	
	Area 57.5 ft x 50 ft		Area 57.5 ft x 50 ft		Area 57.5 ft x 50 ft	
	Left Segment	Right Segment	Left Segment	Right Segment	Left Segment	Right Segment
130-187	143	---	273	---	---	---
187-245	395	---	179	---	---	---
255-312	179	---	130	---	410	---
312-370	90	---	91	---	721	---
380-437	70	54	39	37	271	---
437-495	68	20	32	8	227	---
505-562	43	15	16	11	---	103
562-620	13	12	4	10	---	52
630-687	15	9	2	5	---	33
687-745	4	5	2	2	---	12
755-812	6	4	0	2	8	9
812-870	1	5	4	2	13	5
880-938	1	1	0	2	3	2
938-995	0	0	0	1	2	3
Total	1028	125	772	80	1655	219

Artificial Missiles

The post-shot survey data indicated that the longest range missile was an 8-in. cube originally in a cluster buried 0.5 ft, at a range of 6 ft from GZ, which traveled to range of 340 ft from GZ. While many of the longer-range missiles may have rolled a short distance after impact, the cubic shape of the missiles was selected (in part) to minimize roll, so the surveyed positions of the missiles should not be much more than their ballistic travel distances. The influence of missile size on mean deposition range was evident for those missiles originally located near the surface or close to the silo. The smaller cubes tended to have shorter mean ranges than larger cubes in the same cluster due to air drag effects. More information on the artificial missiles can be found in the final report (Reference 2).

Soil Ejecta

The soil ejecta attributed to the backfill gradations were limited principally to ranges of the order of 200 to 300 ft. Results of this nature appear reasonable based on the relatively low launch velocities and launch angles associated with the explosion configuration.

Strain Gages

Of the 16 strain gages originally positioned in the main QDT-3 structure, 15 recorded during the test. Because strain gages cannot accurately record strains of more than about 5%, the only information gleaned from the resulting records was the times at which certain events might have occurred. The failure times of the entire set of strain gages were found to be within a range of 0.7 to 2.1 ms.

Technical Photography

Of the 13 motion picture cameras installed to photograph debris ejection or impact, 12 operated successfully. The camera which failed to operate was the one installed to obtain high-speed closeup IR photography of the initial venting of the explosion. Unfortunately, the initial silo breakup designed to be captured by the camera with frame speed of about 6000 frames/sec, using normal film, was largely obscured by the emerging fireball. Other cameras provided excellent coverage of the early velocities and angles of large fragments immediately following exit from the expanding dust cloud.

Since the impact ranges of silo debris along the radial survey areas could not be predicted exactly, camera coverage was extended to a range of 510 ft along the northeast

radial and 680 ft on the south radial. Excellent photographs were obtained of the terminal ballistics of debris impacting out to a range of about 600 ft.

A sequence of photographs of the QDT-3 explosion is shown in Figure 10 with a designation of the respective times. The dust cloud reached a maximum diameter of about 100 ft in approximately 0.3 sec, and a maximum height of about 300 ft within a period of 1.8 sec.

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2. Sussholz, B., "Peacekeeper Quantity-Distance Verification Program," BMO-TR-84-17, TRW Defense Group, Redondo Beach, CA, June 1984.

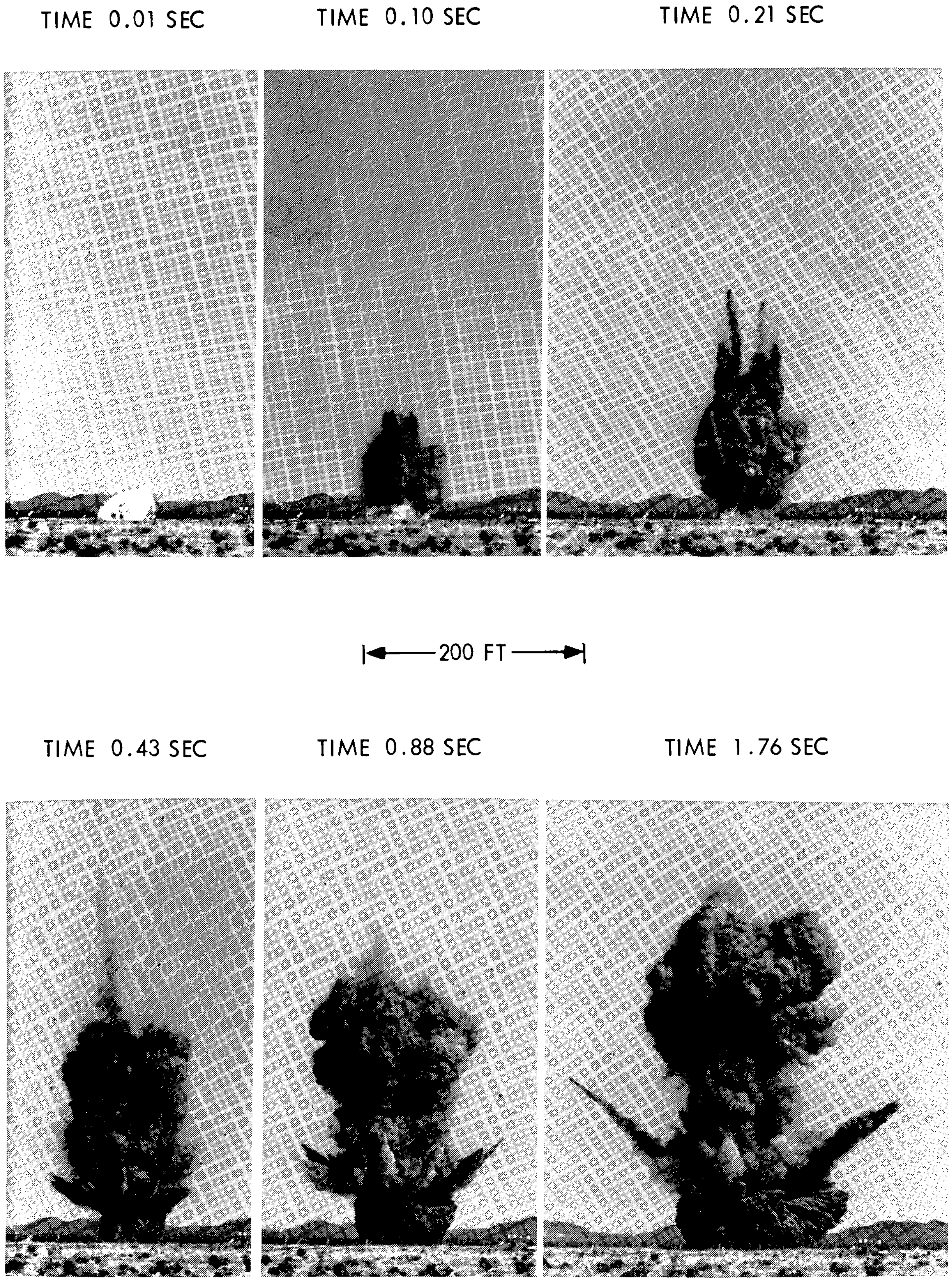

Figure 10. Photographic Sequence of QDT-3 Explosion

PEACEKEEPER QUANTITY-DISTANCE VERIFICATION PROGRAM PART II

TECHNICAL EVALUATION OF QUANTITY-DISTANCE CRITERIA FOR PEACEKEEPER MISSILES IN MINUTEMAN SILOS

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ABSTRACT

A summary is presented of the results of an analytical and experimental program directed toward verification of the quantity-distance criteria associated with an accidental explosion of a Peacekeeper missile in a Minuteman silo. Evaluation of airblast scaling characteristics corresponding to 1/10- and 1/4-scale model tests indicated the applicability of cube-root scaling for in-silo explosions. Structural debris from a 1/4-scale test of a Minuteman silo were analyzed for fragment dimensions, shape factors, and density variation with range. Procedures for debris scaling from the 1/4-scale test data to a full-scale event were developed consisting of a statistical simulation technique and a trajectory limitation approach. Scaling evaluations were performed to determine appropriate quantity-distance values for airblast and fragment hazards corresponding to a full-scale event.

INTRODUCTION

An analytical and experimental program was conducted for the purpose of establishing quantity-distance (Q-D) estimates associated with an explosion of a Peacekeeper missile in an operational Minuteman silo. Aspects of the Peacekeeper Quantity-Distance Verification Program, such as background, program definition, program management, test description and test results are discussed in Part I of a two paper presentation (Reference 1). Results of the analytical and experimental evaluations are summarized in the present paper as Part II. A detailed discussion of the entire program is presented in the final report of the study (Reference 2).

The experimental program consisted of the detonation of high explosive charges within 1/10- and 1/4-scale models of a Minuteman silo. The analytical program was oriented toward evaluation of the scale model test data, development of scaling procedures and establishing Q-D ranges for the airblast and hazardous fragment

phenomena corresponding to a full scale event. The principal objective of the study as noted in Part I was to verify the adequacy of 1750 feet as the quantity-distance for the Peacekeeper system.

The evaluation of Q-D estimates was governed by the following basic criteria:

Airblast - Peak overpressure level of 1 psi.

Fragments - Density of 1 per 600 sq ft with impact energy of 58 ft-lb or greater.

AIRBLAST PHENOMENA

An analytical effort was initiated to determine the airblast characteristics associated with in-silo explosions corresponding to the 1/10-scale tests, QDT-1 and QDT-2, and the 1/4-scale test, QDT-3. Computations were performed with the CSQ II hydrocode developed by Sandia Laboratories/Albuquerque which can treat detonation of high explosives such as Pentolite and TNT. Equations-of-state for high explosives, and other materials including soil, concrete, and air, are available in the code. Results of the calculations incorporated response characteristics of the silo structure and surrounding soil.

Estimates were established of the internal blast loading history which were applied toward a structural fragmentation analysis. Calculations of energy distribution as a function of time indicated that the energy in the Pentolite charge had been reduced by about 65% within a period of approximately 6 msec, with predominant absorption by the concrete and soil in relatively equal proportions with only a few percent being transferred to the air. Results for calculations of the closure-on and closure-off configurations were similar. Within this time frame, the silo launch tube had expanded to about eight times its original volume.

It is of interest to note that detailed comparisons of the overpressure contours for the 1/10- and 1/4-scale calculations for the closure-on configuration indicated excellent agreement in overpressure amplitude and spatial extent, where the 1/10-scale time and distance parameters were scaled by a factor of 2.5 to afford a common frame of reference.

Although the 1/4-scale test was conducted with the closure on, the detailed analysis of the overpressure distribution out to the 1 psi level was performed for the closure-off configuration. The reason for this approach was that certain difficulties developed in the

analysis of the surface venting process for the closure-on configuration due to limitations on the gas diffusion characteristics through mixed cells, i.e., zones in the mesh where gas and solids are both present. The closure-off configuration did not present these difficulties and, as stated above, produced results in substantial agreement with the closure-on configuration.

Because of a computational time constraint, the calculation for the 1/10-scale was terminated at t = 2.4 msec after detonation. The computer running time was such that it appeared advisable to revert to the 1/4-scale calculations prior to completion of the 1/10-scale analysis. The objective was to ensure adequate time for development of a pretest prediction of the ground range to a peak overpressure of 1 psi for the 1/4-scale test.

As far as can be judged from the analytical results covering the extent of parallel calculations for the 1/10-scale and 1/4-scale cases and evaluation of the nature of the computer program, it appears reasonable to conclude that cube root scaling would be inherent in applications to any scale level.

Pretest predictions for the 1/4-scale test indicated that a peak overpressure of 1 psi would occur at a ground range of 202 feet.

DEBRIS SCALING METHODOLOGY

Significant aspects related to development of a debris scaling methodology are assiciated with fragment properties such as number, size distribution, shape factors, drag coefficients, density variation and impact energies. In addition, specification is required of equations of motion to permit determination of fragment propagation characteristics.

Impact Energy Considerations

For the full-scale quantity-distance estimates, it is required that the fragment density not exceed 1 per 600 sq ft for fragments with impact energies equal to or greater than 58 ft-lb. Assuming ballistic trajectories, calculations were made for fragments of various sizes in order to determine a lower bound in principal fragment dimension which would exhibit an impact energy of 58 ft-lb or greater for a broad spectrum of launch velocities and launch angles.

The equations of motion were as follows:

$$\ddot{y} = -g - \frac{1}{2}\frac{C_D \rho_a A}{\rho_c V}\sqrt{\dot{x}^2 + \dot{y}^2}\,\dot{y}$$

$$\ddot{x} = -\frac{1}{2}\frac{C_D \rho_a A}{\rho_c V}\sqrt{\dot{x}^2 + \dot{y}^2}\,\dot{x}$$

where y = vertical component of motion

x = horizontal component of motion

g = acceleration due to gravity

C_D = fragment drag coefficient

ρ_a = density of air

ρ_c = density of concrete

A = fragment cross-sectional area during flight

V = fragment volume

As a frame of reference for fragment parameters during the pretest analyses, the results of the Distant Runner Test Program (Reference 3) were assumed as applicable. Event 5 of the program involved the simultaneous detonation of 48 Mark 82 bombs (explosive weight of 9168 pounds TRITONAL) inside a full scale, reinforced, concrete-hardened aircraft shelter of approximately 185,000 cu ft volume. The concrete debris data were evaluated as to shape and number/size/weight distributions. The shape factor relating the debris weight with a length dimension (or an area) was found to be B = 0.44 for the function:

$$M = B\rho_c L^3 = B\rho_c A^{3/2}$$

where the drag area is assumed equal to L^2. The ratio of area to volume is therefore given by:

$$\frac{A}{V} = \frac{1}{BL} = \frac{1}{0.44L}$$

This value for A/V was substituted into the equations of motion such that ballistic trajectories were dependent on only two variables, namely, principal fragment dimension L and drag coefficient C_D.

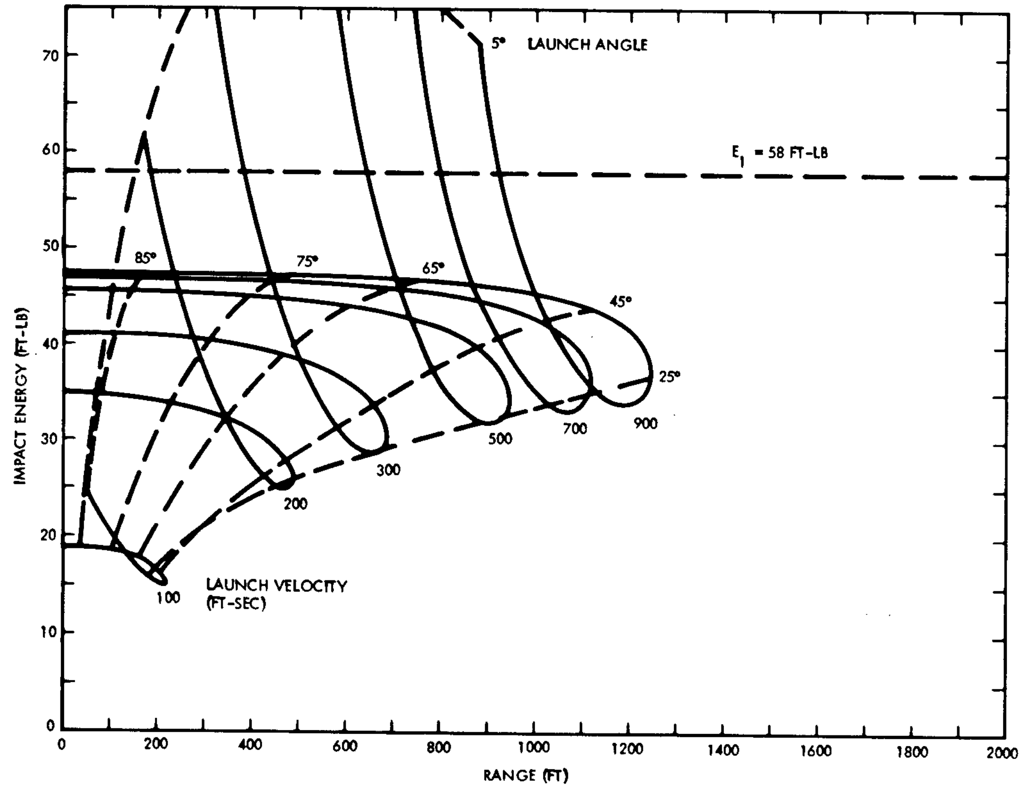
The debris analysis for Distant Runner was limited to fragments with weights equal to or greater than 0.3 pound, which corresponds to a value for L of 2 inches. It was of interest to determine whether this size limitation for full-scale debris distributions would also be applicable for the range of velocities and angles under consideration in the present study.

A comparative plot is shown in Figure 1 of impact energy versus maximum range for fragment lengths of 1.75, 2.00, and 2.25 inches subjected to launch velocities ranging from 100 to 900 ft/sec and launch angles from 5 to 85 degrees with respect to the horizontal. These curves correspond to a drag coefficient of 0.5. For a fragment size of 2.25 inches, most of the contours correspond to impact energies greater than 58 ft-lb. A similar set of contours for a drag coefficient of 1.0 indicate that the minimum fragment length would be 2.50 inches.

It is estimated that the drag coefficients for the broad spectrum of expected fragment shapes and tumbling characteristics would generally fall between the values of 0.5 and 1.0. Therefore, it appears reasonable to conclude that limiting the full-scale fragment lengths to 2 inches and greater would assure that exceedance of the impact energy criterion of 58 ft-lb would automatically be satisfied and would not require any further consideration. Based on the assumption of geometric scaling, the fragment measurements associated with the 1/4-scale test were limited to principal dimensions of 1/2-inch and greater. In addition, a lower bound to fragment weight was assumed to be 0.3/64 = .0047 lb or 2 gm, where 0.3 lb corresponds to a 2-inch fragment and 2 gm to a 1/2-inch fragment.

One requirement of the analytical program was to develop a theoretical debris scaling model which would relate results from the one-quarter scale QDT-3 data to the required full-scale debris distribution estimates. Two approaches were developed, one governed by a statistical simulation technique, and the other by a trajectory limitation technique. These methods appeared to offer independent procedures toward establishing reasonable bounds for full-scale debris criteria. A description of the two methods follows.

L = 1.75"



L = 2.00"

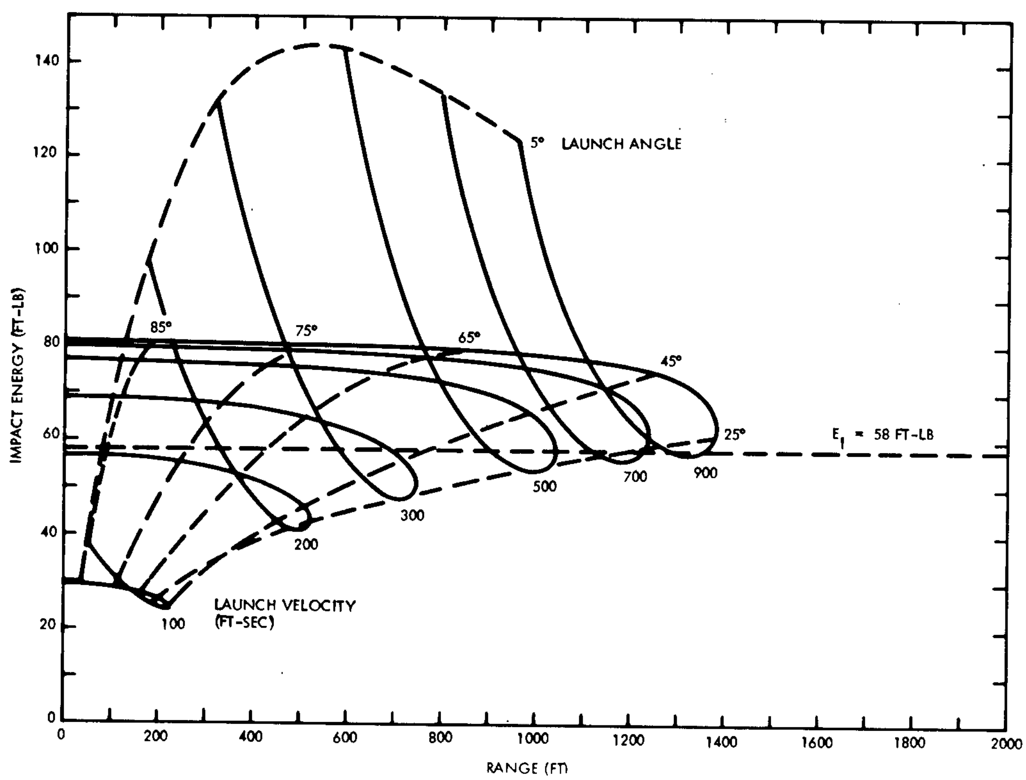


Figure 1. Fragment Size Limitation for Impact Energy Criterion

L = 2.25"

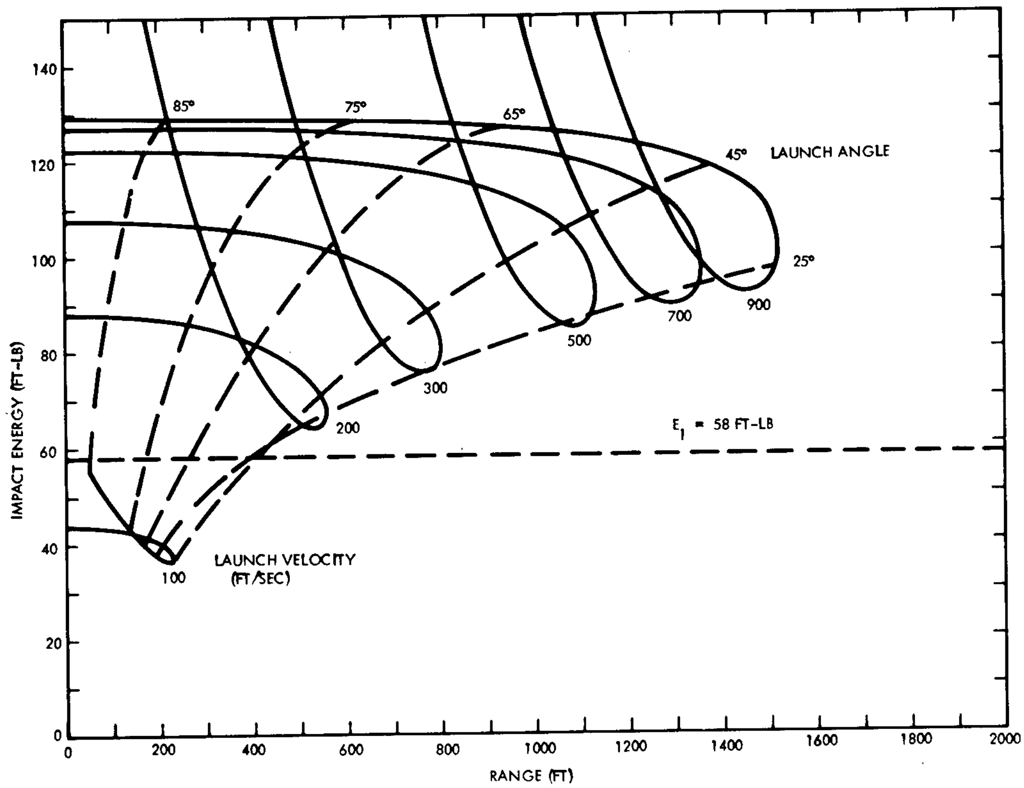


Figure 1. Fragment Size Limitation for Impact Energy Criterion (Continued)

Statistical Simulation Method

The procedures associated with the statistical simulation technique are illustrated in Figure 2. The basic steps are summarized as follows:

- Estimate fragment length categories, size gradient, and total number.
- Establish a band of launch velocities and launch angles of interest and identify appropriate probability factors for various combinations of velocity and angle.
- Compute maximum fragment ranges based on ballistic trajectories for respective length categories, launch parameters, shape factors, and drag coefficients.
- Determine the number of fragments in each length category by the summation of weight factors associated with the specific velocity and angle combinations.
- Tabulate the maximum ranges for each individual length category within progressive range segments of equal increments.
- Assess the total number of fragments in each range segment by application of the designated weight factors.

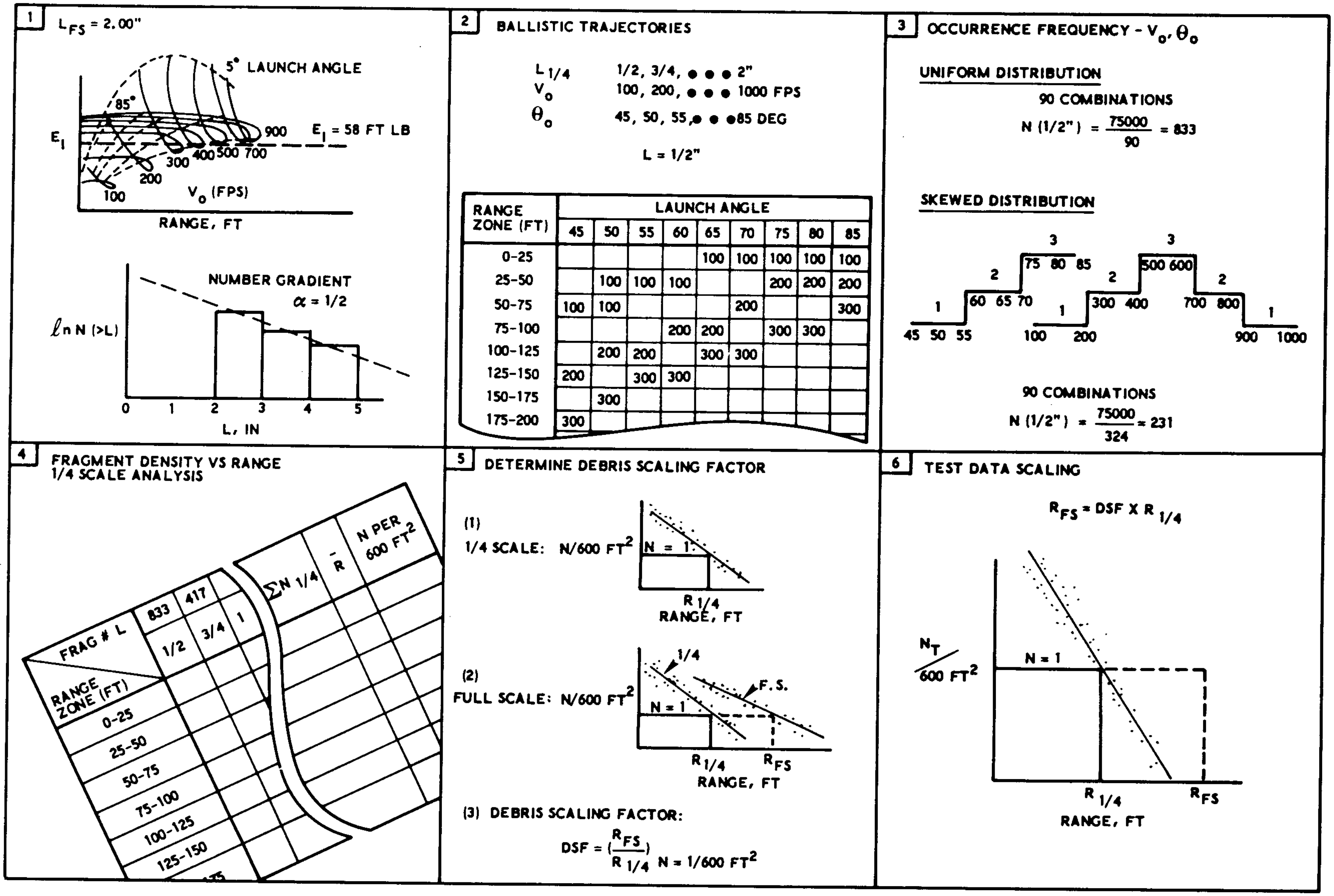


Figure 2. Debris Scaling Procedures by Statistical Simulation Method

- Calculate the fragment density distribution as a function of range.

- Repeat set of calculations for each length category for a fragment dimension of 4L.

- Evaluate the debris scaling factor (DSF) which is determined as the ratio of ranges for a debris density of 1 fragment per 600 sq ft for the L and 4L cases (scaling approach A of Table 1).

The statistical simulation method was applied to 12 different cases in order to evaluate the sensitivity of the debris scaling criteria to variations in various parameters. Assumptions for the respective cases and associated analytical results are shown in Table 1.

For launch velocity and angle combinations, two types of distributions were assumed, namely:

1) Uniform Distribution - Equal probability of occurrence of any combination of velocity and angle values from the set of V_o = 100 to 1000 ft/sec, in increments of 100 ft/sec, and θ_o = 45 to 85 degrees from the horizontal, in increments of 5 degrees.

2) Skewed Distribution - Weighted probability of occurrence of velocity and angle combinations as shown in Panel 3 of Figure 2.

With reference to the drag coefficients, a value of either 0.5 or 1.0 was applied. For the number gradient parameter, a range of values of 3/8, 1/2, and 2/3 was covered, which corresponds to a measure of the relative occurrence frequency for successive length categories such as L and L + 1/4-inch.

Three scaling approaches were applied as denoted by A, B, and C in Table 1. For scaling approach A, a ratio was taken of the 1/4-scale and full-scale ranges in each case corresponding to a debris density of 1 per 600 sq ft.

The procedure for scaling approach B was to determine by trial and error a debris density for the 1/4-scale case designated by λ^2, such that if the associated range is multiplied by λ the result would be the same as the full-scale range for a density of 1 per 600 sq ft.

The third technique, designated as scaling approach C, consists essentially of determining the range for the 1/4-scale analysis where the fragment density is 16, and

Table 1. Comparison of Debris Scaling Evaluations by Statistical Simulation Method

				Scaling Approach A			Scaling Approach B				Scaling Approach C				
Case	Launch V_o and θ_o Spectrum	Drag Coefficient	Number Gradient	$R_{1/4}$ for 1/600 ft^2 (ft)	$(R_{FS})_1$ for 1/600 ft^2 (ft)	$\frac{(R_{FS})_1}{R_{1/4}}$	Scale Factor λ	λ^2	$R_{1/4}$ for λ^2/600 ft^2 (ft)	$(R_{FS})_1$ for 1/600 ft^2 (ft)	Scale Factor λ	λ^2	$(R_{1/4})_4$ for 16/600 ft^2 (ft)	$(R_{FS})_4$ for 1/600 ft^2 (ft)	$\frac{(R_{FS})_4}{(R_{FS})_1}$
1*	Uniform	1/2	1/2	848	1644	1.93	2.72	7.4	604	1644	4	16	512	2048	1.24
2	Uniform	1/2	2/3	1020	1999	1.96	2.88	8.3	694	1999	4	16	593	2322	1.19
3	Uniform	1/2	3/8	732	1446	1.98	2.74	7.5	528	1446	4	16	453	1812	1.25
4	Skewed	1/2	1/2	773	1572	2.03	2.88	8.3	546	1572	4	16	475	1900	1.21
5	Uniform	1	1/2	553	1249	2.26	3.11	9.7	402	1249	4	16	367	1468	1.18
6	Skewed	1	1/2	516	1150	2.23	3.11	9.7	370	1150	4	16	336	1340	1.16
7	Uniform; Scaling 2:1	1/2	1/2	848	1704	2.01	2.88	8.3	591	1704	4	16	512	2048	1.20
8	Uniform; $2N_o$	1/2	1/2	932	1889	2.03	2.76	7.6	684	1889	4	16	596	2348	1.26
9	Uniform; $1/2N_o$	1/2	1/2	764	1398	1.83	2.64	7.0	530	1398	4	16	427	1708	1.22
	Average					2.03	2.86	8.2							1.21
10**	Skewed	1/2	1/2	670	1159	1.73	2.10	4.4	552	1159	4	16	450	1800	1.55
11	Skewed	1/2	2/3	750	1310	1.75	2.12	4.5	616	1310	4	16	504	2016	1.54
12	Uniform	1/2	2/3	712	1140	1.60	2.14	4.6	531	1140	4	16	384	1536	1.35

*Cases 1-9: Distant Runner shape factors - pretest calculations
**Cases 10-12: QDT-3 shape factors - post-test calculations

multiplying this range by $\sqrt{16}$ or 4 to determine a full-scale range corresponding to a density of 1 per 600 sq ft. This approach is related to standard procedures of geometric scaling, which is readily recognized as conservative since the drag effects are non-linear as the fragment sizes are scaled by a factor of 4.

The purpose of evaluating the relative merits of scaling approaches A and B was to determine whether either method reflected a parameter that was relatively insensitive to the broad variations in analytical assumptions. The standard deviation of the values for approach A was about 6% from the mean, whereas, for approach B, the standard deviation was approximately 12%. It appears that approach A is somewhat more favorable and, therefore, was selected as one of the methods for scaling the 1/4-scale test results.

As a representative example, the analytical results for Case 11 are shown in Figure 3. For a density of 1 per 600 sq ft, the calculated 1/4-scale and full-scale ranges are 750 and 1310 feet, respectively. The associated debris scaling factor for scaling approach A is, therefore, 1310/750 or 1.75. For the case of scaling approach B, the 1/4-scale range for a density of 4.5 per 600 sq ft, where $\lambda^2 = 4.5$, is 616 feet. Multiplying this range by a λ value of 2.12, one finds $616 \times 2.12 = 1307$ feet, or essentially equivalent to the analytical result of 1310 feet. The full-scale range obtained by scaling approach C is 2016 feet, which is 55% greater than the calculated range, indicating a high degree of conservatism by this type of approximation.

The parameters corresponding to Case 11 were a reasonable representation of the debris characteristics associated with the 1/4-scale test, and, therefore, a debris scaling factor of 1.75 was assumed for the quantity-distance scaling evaluation.

During the course of the study, a comprehensive effort was initiated to determine appropriate drag coefficients for the fragments of interest. High speed photography for the 1/4-scale test indicated substantial tumbling among fragments of all sizes. A literature survey yielded considerable data for drag effects associated with constant cross-sectional areas for bodies of various shapes; however, there appeared to be no information regarding tumbling fragments. Discussions with several sources indicated a consensus that the drag effect for a tumbling fragment was most probably comparable to that of a sphere. Therefore, for the purpose of the study an assumption was made to apply scale factors based on a drag coefficient of 0.5 toward development of Q-D estimates.

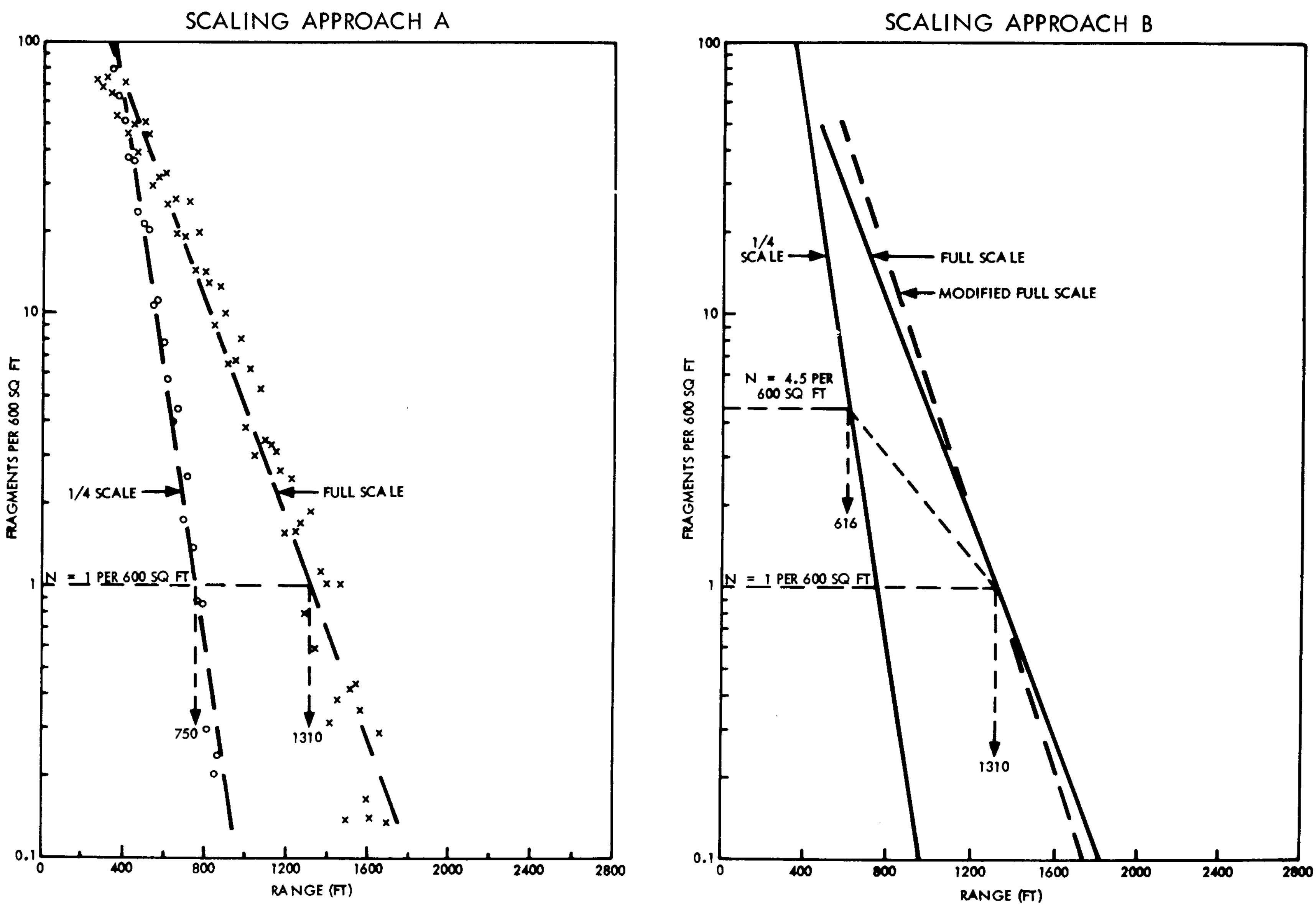


Figure 3. Case 11 - Debris Density Scaling by Statistical Simulation Method

Trajectory Limitation Technique

The trajectory limitation technique for debris scaling is based on an evaluation of the ratio of the maximum ranges of fragments of various 1/4-scale dimensions and corresponding full-scale dimensions for similar launch parameters.

The initial approach in development of the method considered determination of a range multiplication factor for each of the respective length categories and scaling the 1/4-scale range for each fragment to its appropriate full scale range. After converting all of the QDT-3 debris data in this manner, an analysis could be performed to determine the full-scale range for a fragment density of 1 per 600 sq ft.

A family of contours is shown in Figure 4 representing the results of ballistic trajectory calculations for launch velocities of 200 to 1000 ft/sec and launch angles of 5 to 85 degrees associated with several fragment lengths. These curves were developed on the basis of the QDT-3 shape factors after evaluation of the test data. A pretest set of curves based on the Distant Runner shape factor were applied initially toward development of the trajectory limitation method. The rationale is similar although the scaling parameters are different for the two shape factors.

In Figure 4(a) the abscissa scale indicates the maximum range R_1 for a 1-inch fragment, and the ordinate scale represents the ratio R_4/R_1 of maximum ranges for 4-inch and 1-inch fragments when subjected to the same set of launch parameters. A similar family of contours is depicted in Figure 4(b) for comparison of the response characteristics of 2-inch and 8-inch fragments. For these calculations, the drag coefficient was assumed to be 0.5.

With reference to Figure 4(a), it appears that, encompassing all launch parameters, an upper bound in scaling from ranges for 1-inch fragments to ranges for 4-inch fragments would be to multiply the 1/4-scale ranges by a factor of 2.24. In essence, application to QDT-3 would mean multiplying the range observed for each 1-inch fragment by this factor in order to establish the appropriate range for a corresponding 4-inch fragment from a full-scale event. The value of 2.24 was selected for λ since λ^2 has an integral value of 5 for the 1/4-scale density per 600 sq ft. For the case of scaling from 2-inch to 8-inch fragments, the associated range multiplication factor corresponding to an upper bound criterion is also approximately 2.24 as determined from the curves presented in Figure 4(b).

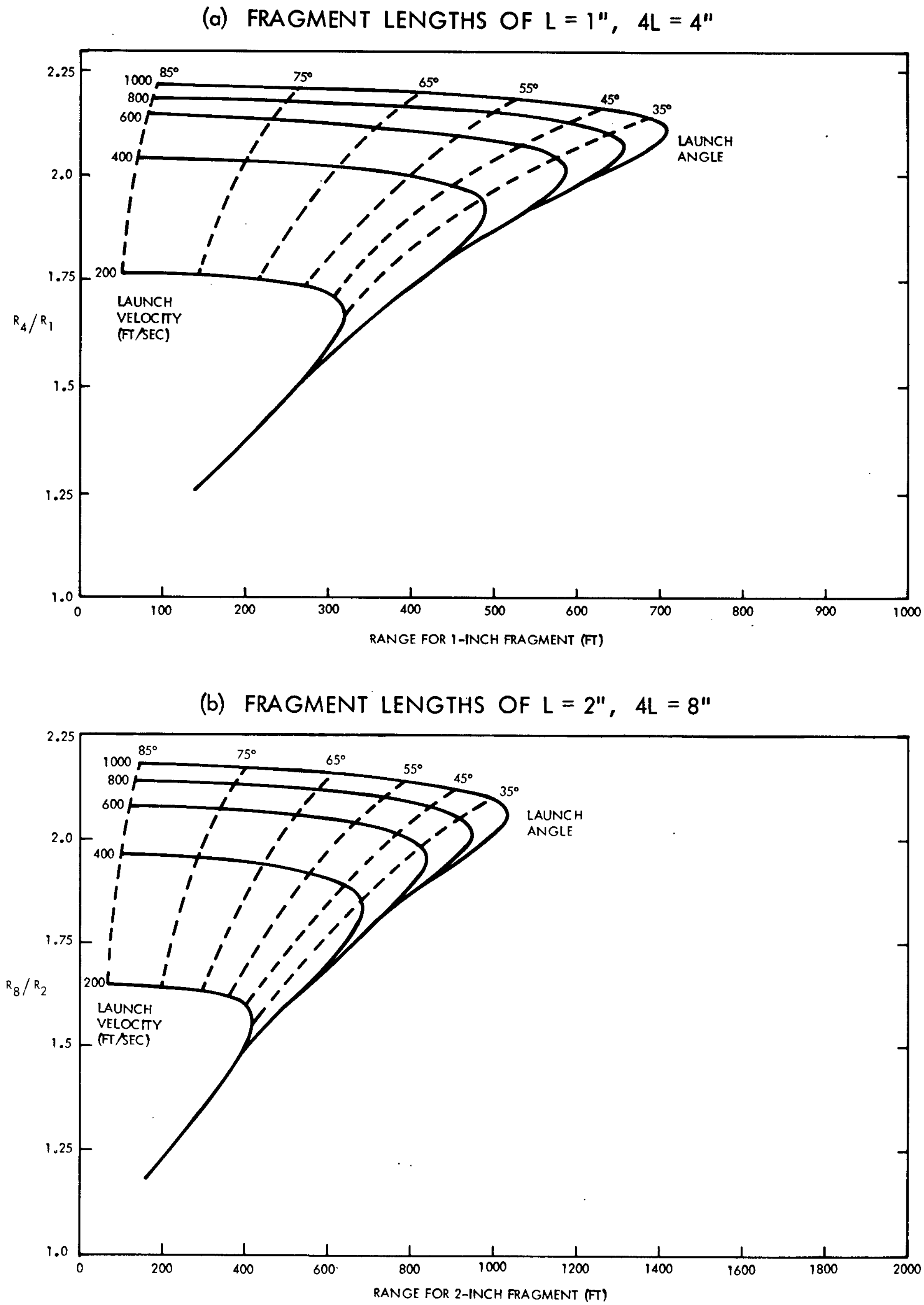


Figure 4. Comparison of Maximum Range Ratios Corresponding to QDT-3 Fragment Shape Factors and Drag Coefficient of 0.5

Table 2 presents an evaluation of R_{4L}/R_L for various lengths corresponding to a drag coefficient of 0.5. It appears that a single value of about 2.24 would encompass all cases of interest and establish an upper bound for a spectrum of launch velocities up to 1000 ft/sec. Based on the convergence of the contours in Figure 4, the value of 2.24 would be applicable within a few percent to higher velocities.

Table 2. Upper Bound Range Multiplication Factors

Fragment Length (in.)		R_{4L}/R_L
1/4 Scale	Full Scale	
0.50	2	2.36
0.75	3	2.24
1.00	4	2.22
1.50	6	2.21
2.00	8	2.18
	Average	2.24

For the application of a single range multiplication factor covering all fragment dimensions of interest, a considerable simplification occurs in the scaling of QDT-3 data to full scale. The procedure in this event is to consider 2.24 as equal to λ, as defined for the statistical simulation method. Determine the range for the QDT-3 debris density distribution corresponding to a density of 5 fragments for 600 sq ft, and multiply this range by 2.24 to obtain the required full-scale range for a density of 1 per 600 sq ft.

Figure 5 illustrates the set of procedures associated with the trajectory limitation method. A representative scaling example is shown in Panel 3 for the case of $\lambda = 2$. Since the area increases by a factor of 4 as the range is doubled, it is necessary that the 1/4-scale density be 4 per 600 sq ft to result in a full scale density of 1 per 600 sq ft.

TEST DATA ANALYSIS

Airblast

The quantity-distance test (QDT) program consisted of two 1/10-scale and one 1/4-scale tests. A net explosive weight of 202,000 pounds of TNT was assumed for the Peacekeeper missile propellants. The specified Pentolite charge weights for QDT-1 and QDT-2, the two 1/10-scale tests, were equivalent to $202{,}000/(10)^3$ or 202 pounds of TNT.

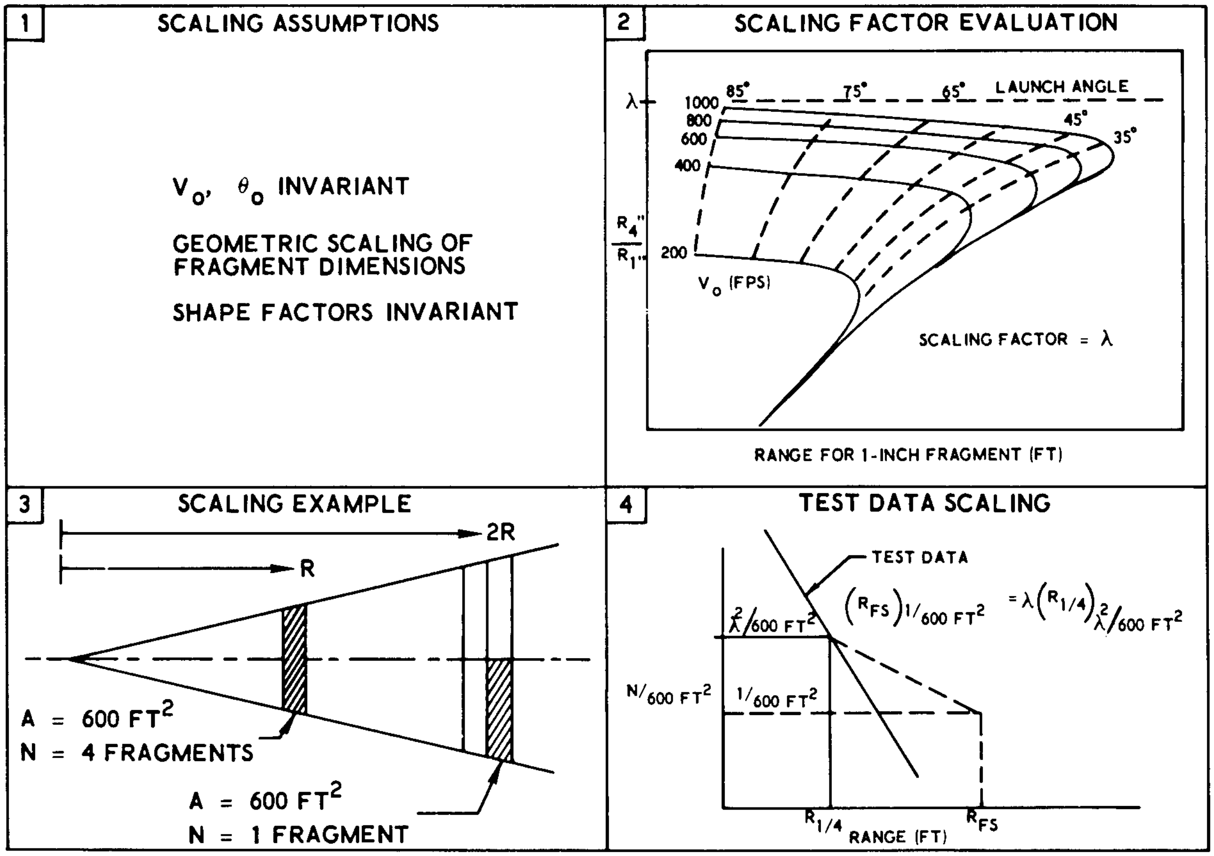


Figure 5. Debris Scaling Procedures for Trajectory Limitation Method

For QDT-3, the 1/4-scale test, the Pentolite charge was equivalent to $202{,}000/(4)^3$ or 3156 pounds of TNT. Blast measurements were made on all tests, whereas debris/ejecta data were acquired only for the 1/4-scale test.

A comparative plot of peak overpressures versus range is presented in Figure 6(a) for the following data:

- Average values of QDT-1 and QDT-2 peak overpressures with associated ranges scaled to QDT-3 ranges by multiplication by the scale factor of 2.5.
- QDT-3 test results.
- QDT-3 analytical prediction.

It is evident that cube root scaling of peak airblast overpressure is readily applicable between the 1/10-scale and 1/4-scale events. This conclusion is substantiated for other airblast parameters such as positive duration and arrival time by the data comparisons presented in Figure 6(b). Comparison of airblast waveforms on the basis of scaled time and range also indicated good agreement.

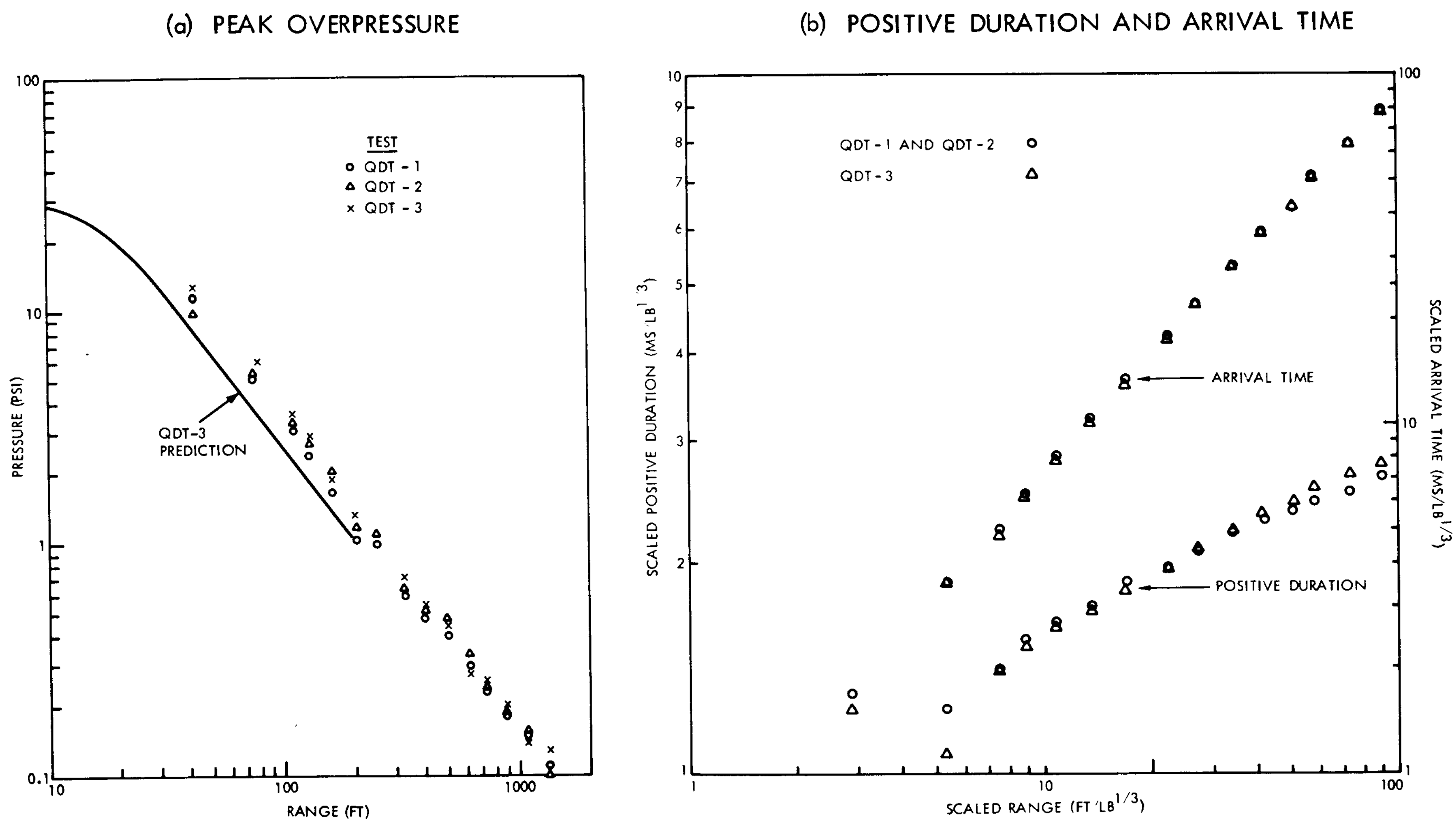


Figure 6. Scaling Comparison of QDT Airblast Results

Although the analytical curve is somewhat lower than the test data, the agreement is considered good, since it was anticipated that the predicted peak overpressures would be lower due to a rounding of the sharp shock front caused by the computer zoning process inherent in th finite element method. The analytical curve predicted a ground range of 202 feet for an overpressure level of 1 psi. The QDT-3 data in Figure 4(a) indicates a ground range of 270 feet for the same overpressure of 1 psi.

The blast pressure data for QDT-3, plotted in Figure 7(a), indicates a divergence at the lower pressure levels among the data from the NW radial as compared to the results for the S and NE radials. This effect is attributable to the wind bias at surface elevation. The wind velocity was about 10 mph downwind as the airblast wave propagated along the NW radial, and thereby enhanced the pressure amplitude, whereas for the S and NE radials, the wind velocity was about 5 mph in a direction opposite to blast propagation causing a pressure reduction.

At shot times, the ambient pressures at the test sites were generally about 12.5 psi. The average elevation of the 100 Wing V Peacekeeper sites of interest is about 5100 feet, which is quite comparable to the test site elevation of approximately 4900 feet. Therefore, it was concluded that the test data would be directly applicable to an operational event without requiring a correction factor for ambient pressure differences.

A calibration shot consisting of a surface burst of a 1000-pound tangent sphere was conducted for the purpose of evaluating the reliability of the QDT sensors and recorders as a total integrated system. This test was conducted at the same ground zero as QDT-3, permitting utilization of the same blast gage array. Excellent agreement is observed between the recorded blast data and the pretest predictions (solid curve) as shown in Figure 7(b).

A comparison is shown in Figure 7(b) of the curve for the 1000 pound TNT surface burst and the contour obtained in Figure 7(a) from the QDT-3 test results. The two curves are parallel for pressure levels of 10 psi and less, indicating that one can approximate the QDT-3 contour by means of a surface burst of an equivalent TNT charge. Based on cube root scaling, the equivalent charge is estimated to be given by $1000\,(270/422)^3 = 262$ pounds. The actual QDT-3 test charge was determined to be 2685 pounds of Pentolite with a TNT equivalence of 3034 pounds. Therefore, the relative blast efficiency of the QDT-3 explosion as compared to a surface burst was 262/3034, or 8.6%.

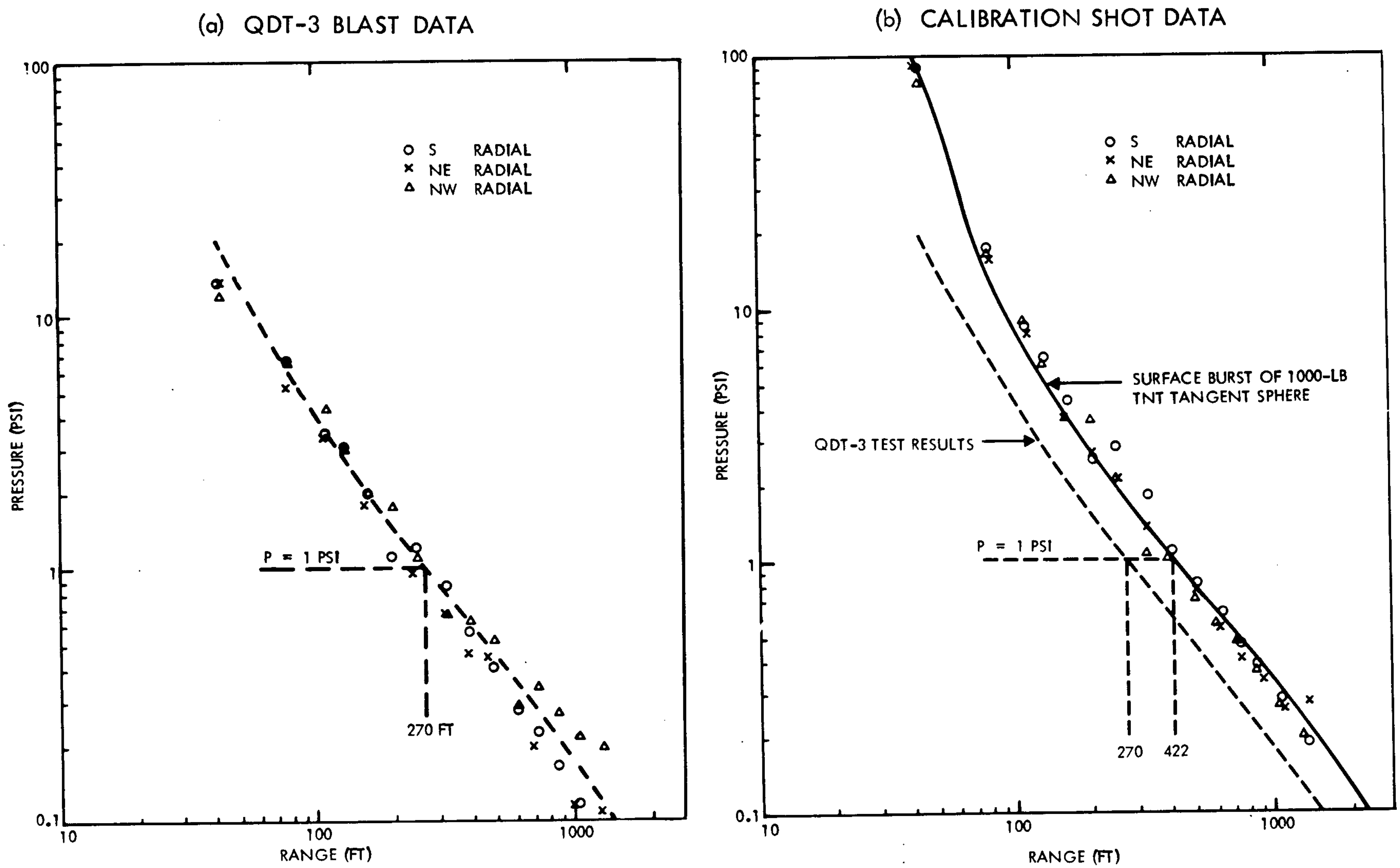


Figure 7. QDT-3 Airblast and Calibration Shot Data

Soil Ejecta

Fragments resulting from an in-silo explosion include structural debris and soil ejecta. Basic sources of soil ejecta are boulders, rocks, and pebbles, inherently characteristic of the Minuteman Wing V sites of interest, and large earth clumps that may evolve as a result of the natural cementation and cohesiveness of the soil particulate.

Backfill specifications for the 1/4 scale test site were based on a direct simulation of soil conditions at operational sites using gradations, density and stress-strain properties. Since the precise soil cohesivity representative of media surrounding Wing V silos could not be reproduced, estimates of size, number, and trajectories, as related to large earth clumps, were developed primarily on the basis of an analytical evaluation.

Test results indicated that the soil ejecta attributed to the backfill material were limited principally to ranges of the order of 300 feet or less. Results of this nature appear reasonable based on the relatively low ejecta launch velocities ($\leq$250 ft/sec) and launch angles ($\leq$45 degrees) associated with the explosion configurations.

The gradations of the Q-D soil were intended to be similar to the operational site characteristics and, therefore, the ejecta sizes should be the same for the full-scale event as compared to the QDT-3 distribution, with the number of ejecta in each size category being enhanced by a factor of 64 for conservation of mass. Since the maximum QDT-3 range for the ejecta was about 300 feet, a range of approximately 500 feet was evaluted for a density of 1 per 600 sq ft for the full-scale in-silo explosion with higher fragment densities at closer ranges. This conclusion is predicated on the assumption that the launch velocities and launch angles are similar between the 1/4-scale and full-scale events. It appears, therefore, that soil ejecta will not be of major significance toward quantity-distance considerations.

With reference to the possible occurrence of large earth clumps due to the natural cohesiveness of the soil particulate, an upper bound evaluation indicated that, for a full-scale explosion, the range to a fragment density of 1 per 600 sq ft, was estimated to be approximately 1600 feet. The analysis associated with this result was based on the assumption that 10% of the soil fractured like rock. The value of 10% is considered to be highly conservative, perhaps by an order of magnitude, and was applied for the purpose of determining an upper bound estimate of safe distance for earth clumps for comparison with the ground range of 1750 feet of interest. It appears reasonable to conclude that the

impact of earth clumps in the evaluation of quantity-distance for a full-scale event is negligible.

Structural Debris

As a frame of reference for the following analysis, Table 3 presents a summary of the number of concrete fragments located within the S, NE, and NW radials from ranges of 125 to 1000 feet. This set of data is also presented in Part I as part of the test results.

The variation of QDT-3 debris density with azimuth at a range of 400 feet is plotted in Figure 8. It is quite evident that the density distribution is approximately skew symmetric in the direction of the NW radial due to the effect of the wind velocities at shot time. The surface wind velocity was 10 mph in an azimuth direction of 110 degrees relative to true North.

In consideration of the impact on drag effects, a question of particular significance is the nature of the shape factors for the QDT-3 fragment distribution. As noted earlier the drag effects are dependent on the ratio A/V in the equations of motion.

Since photographic data indicated that tumbling was quite typical for most fragments, an average cross-sectional area was assumed to be given by the following relation:

$$A = \frac{1}{3} (L_1L_2 + L_1L_3 + L_2L_3)$$

where L_1 is the principal dimension and L_2 and L_3 are the other two dimensions measured orthogonally. The area shape factor was designated as β and defined by:

$$\beta = \frac{A}{L_1^2}$$

The volume of the fragment was determined by the weight divided by the density of concrete. The volume shape factor was designated as α and defined by:

$$\alpha = \frac{V}{L_1^3}$$

Table 3. QDT-3 Debris Data Summary

Range (ft)	Radial Area 3 (10 ft x 10 ft) S	NE	NW
125	135	122	126*
250	67	49	188
375	18	15	60
500	11	2	42
625	0	1	7
750	0	0	4
875	0	0	2
1000	2	0	2
Total	233	189	431

Number of Fragments 4732

Area $A_o = 190,900\ ft^2$

Total Area
$A_T = \pi(1000^2 - 125^2)$
$= 3,090,000$ ft

$\frac{A_o}{A_T} = 6.2\%$

Total Number of Fragments

$N_T = \frac{4732}{0.062} = 76,300$

*Data for two witness sheets

Range (ft)	S Radial Area 57.5 ft x 50 ft		NE Radial Area 57.5 ft x 50 ft		NW Radial Area 57.5 ft x 50 ft	
	Left Segment	Right Segment	Left Segment	Right Segment	Left Segment	Right Segment
130-187	143	---	273	---	---	---
187-245	395	---	179	---	---	---
255-312	179	---	130	---	410	---
312-370	90	---	91	---	721	---
380-437	70	54	39	37	271	---
437-495	68	20	32	8	227	---
505-562	43	15	16	11	---	103
562-620	13	12	4	10	---	52
630-687	15	9	2	5	---	33
687-745	4	5	2	2	---	12
755-812	6	4	0	2	8	9
812-870	1	5	4	2	13	5
880-938	1	1	0	2	3	2
938-995	0	0	0	1	2	3
Total	1028	125	772	80	1655	219

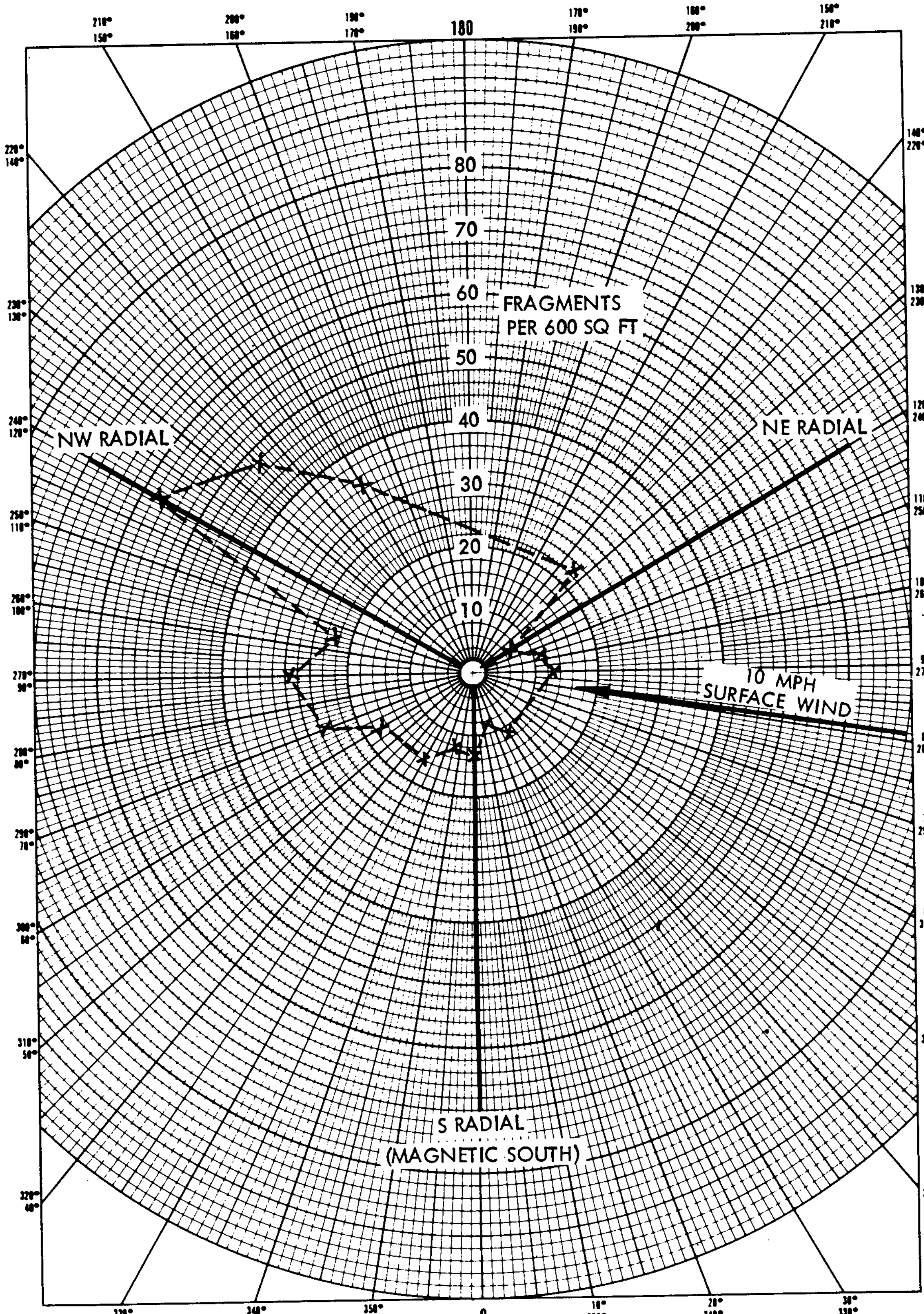


Figure 8. Fragment Density Variation with Azimuth at 400-Foot Range

As a representative example, the mass distribution for 796 one-inch fragments (L_l = 1 in.) is plotted in Figure 9. The average volume shape factor, α, is determined to be 0.17. This value is significantly lower than the uniform value of 0.44 for all fragment lengths reported for the Distant Runner test data (Reference 3). The average QDT-3 weight for a 1-inch fragment was 6.5 gm, whereas a value of 16.7 gm would correspond to the Distant Runner shape factor.

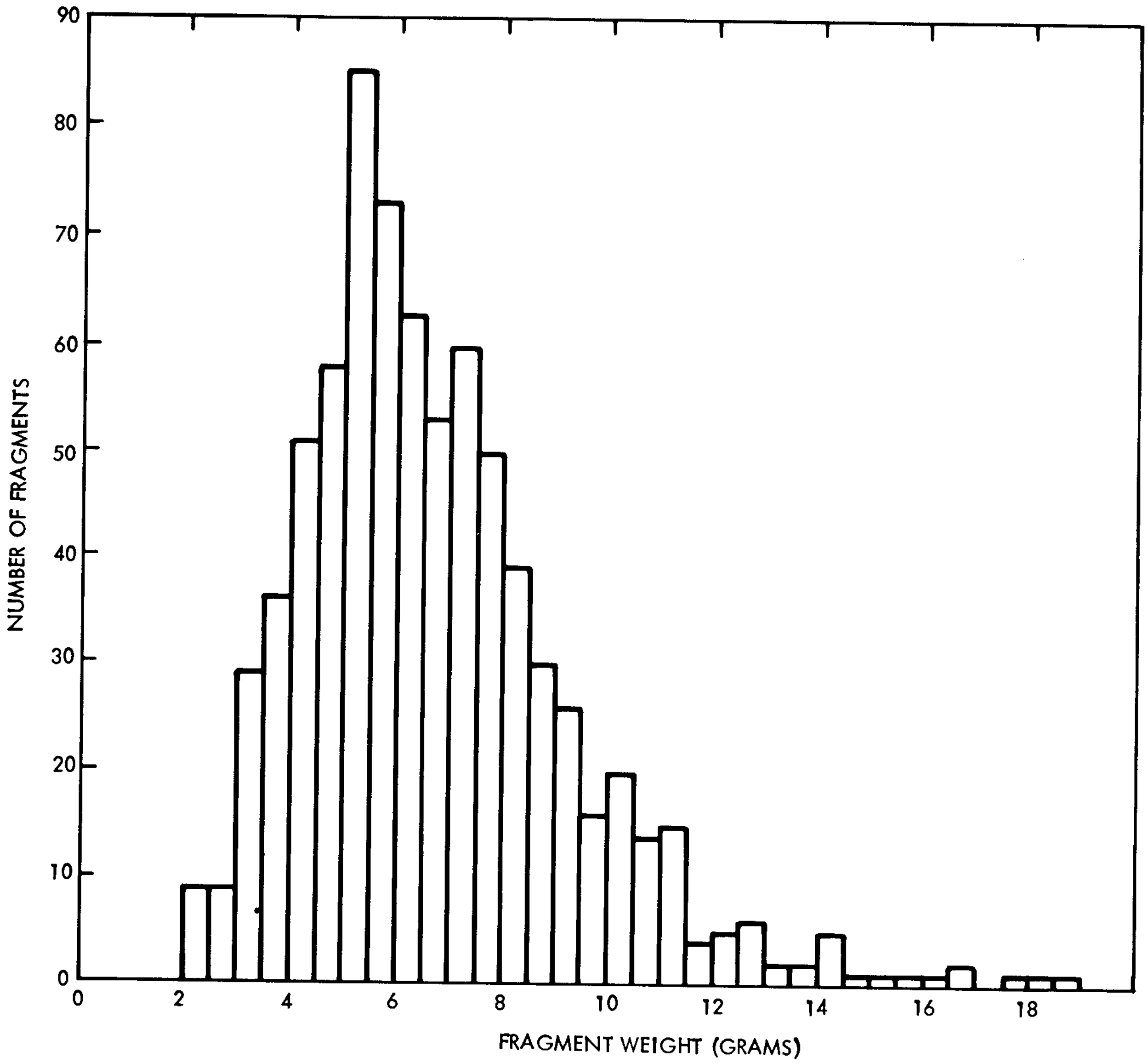


Figure 9. QDT-3 Mass Distribution for 1-Inch Structural Fragments

Similar evaluations were performed for fragments of other principal lengths. The data were analyzed to determine the variation of shape factors α and β with length. A plot is shown in Figure 10 of α and α/β as a function of principal fragment dimension L. Over the range of fragment lengths of 1/2 inch to 8 inches, the value of α/β decreased

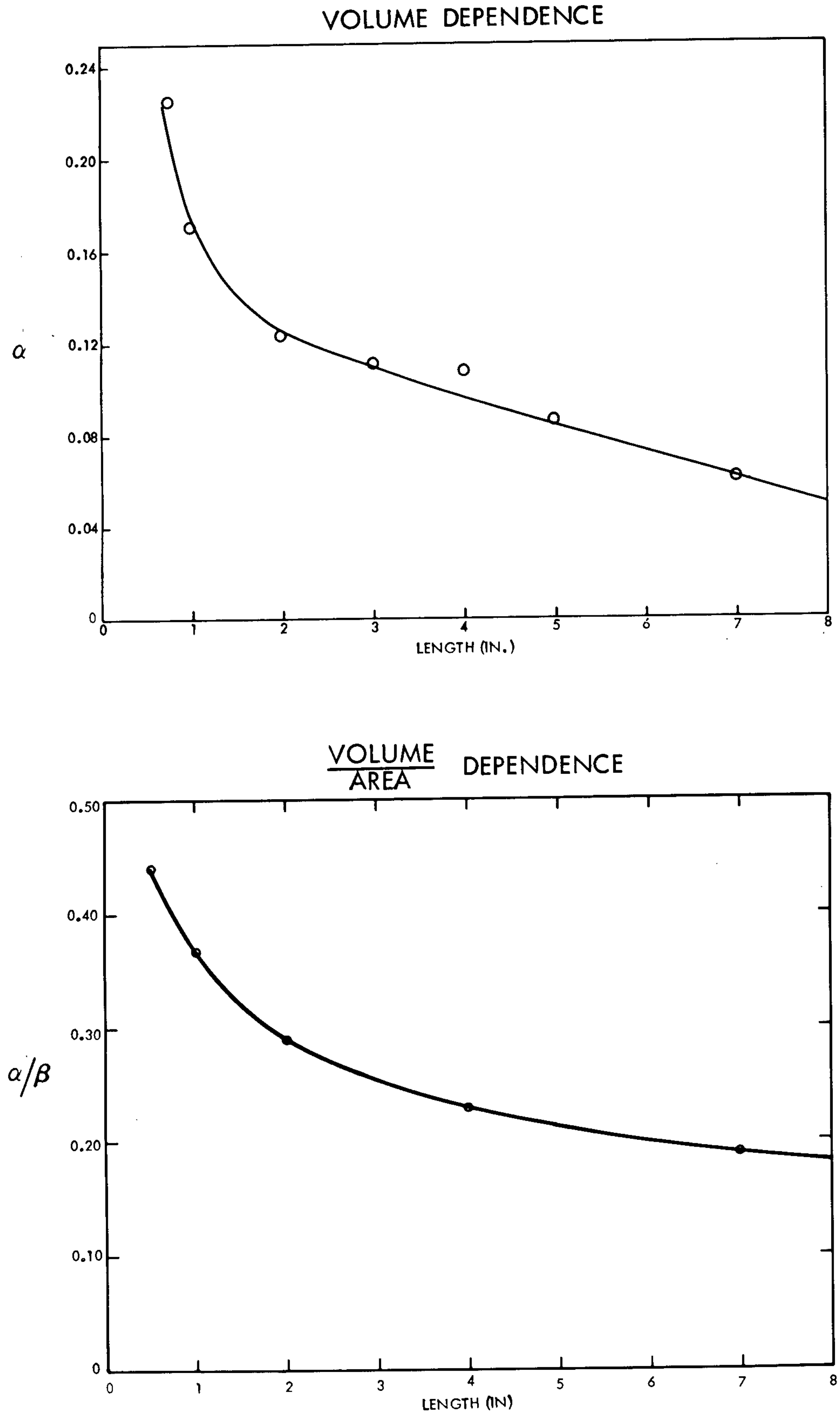


Figure 10. QDT-3 Frag ment Shape Factor Variation with Length

from 0.44 to 0.17. In the equations of motion, the factor A/V would be represented by $1/(\alpha/\beta)L$. Therefore, the drag of an 8-inch fragment would be reduced only by a factor of about 6, relative to drag for a 1/2-inch fragment, as compared to a reduction by a factor of 16 for the case of constant shape factor. The higher drag effects for larger fragments result in lower maximum ranges in the analysis for a full-scale event.

A possible explanation for the difference between the QDT-3 and Distant Runner shape factors is that more forceful shattering effects occurred on the reinforced concrete during QDT-3 where the charge density relative to test volume was about 12.5 lb/cu ft as compared to the Distant Runner density of 0.05 lb/cu ft or a ratio of about 250. The QDT-3 internal pressure levels on various structural elements were of the order of thousands of psi and greater, whereas the Distant Runner levels were in the range of tens of psi. The highly nonlinear reflection coefficients for shock waves contributed to a greater enhancement of the loading effects during QDT-3.

Estimates were established of the debris density per 600 sq ft as a function of range for the composite set of data covering the S, NE, and NW radials and for the NW radial separately. The estimate for only the NW radial data constitutes an assumption that this extreme distribution is representative of the total area in all directions and, therefore, corresponds essentially to a conservative upper bound value. A plot of the density data for fragments with principal dimension $\geq 1/2$ inch is presented in Figure 11 as a function of range, with the following exponential functions developed on the basis of a least squares fit.

S, NE, and NW radials: $$N_{1/4} = e^{6.3\left(1 - \frac{R}{812}\right)}$$

NW radial only: $$N_{1/4} = e^{7.6\left(1 - \frac{R}{896}\right)}$$

where $N_{1/4}$ is the QDT-3 number of fragments per 600 sq ft and R is the range in feet. The range corresponding to a density of 1 per 600 sq ft is 812 feet for the first relation and 896 feet for the second relation.

A structural fragmentation analysis was performed which yielded estimates of the fragment distribution for the QDT-3 test. There was good correlation between predictions and test results for both small and large fragments. For the case of small fragments

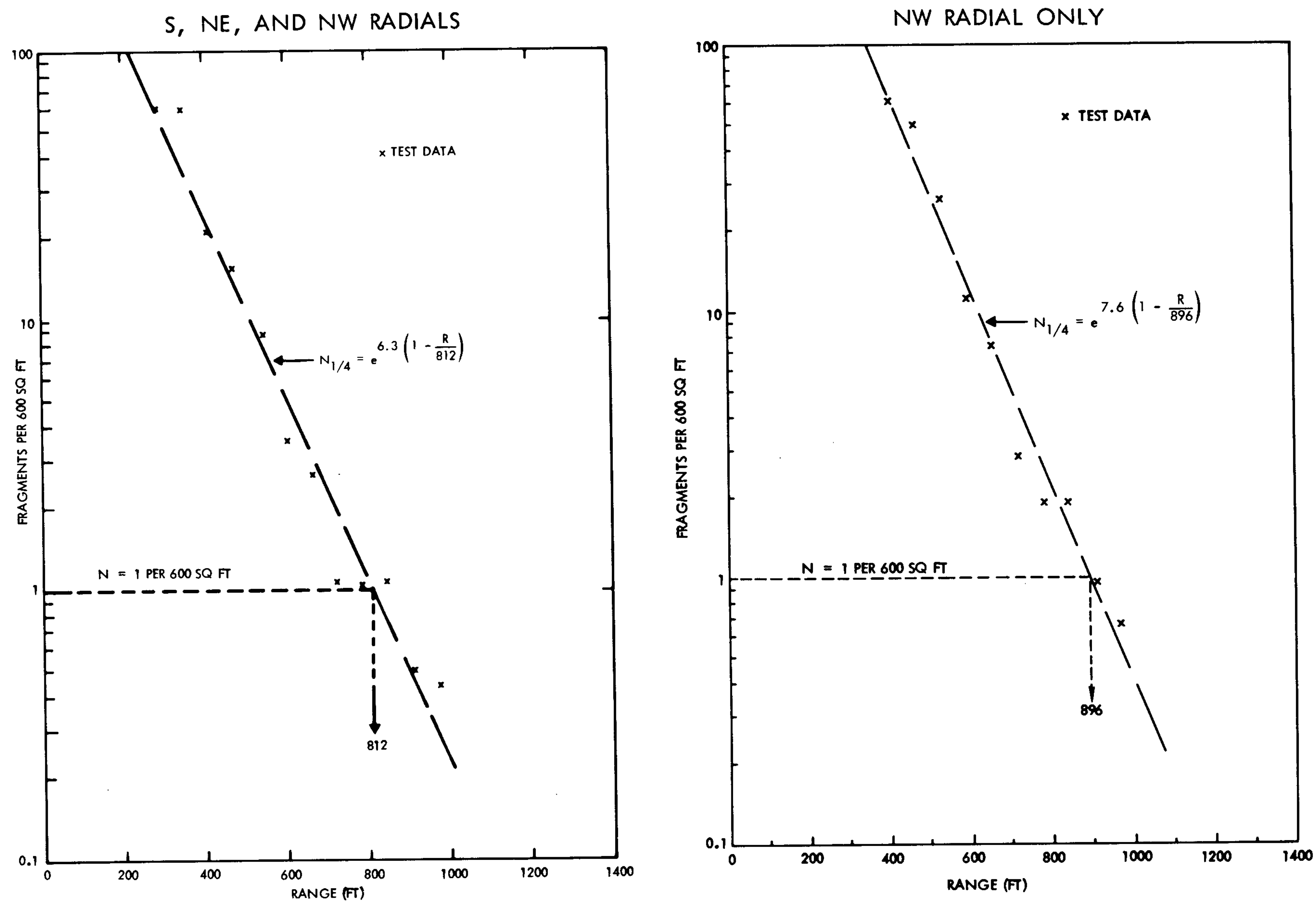


Figure 11. QDT-3 Debris Density Distribution

a density of 1 per 600 sq ft was predicted at a range of 721 ft. Evaluation of the test data indicated the range to be 812 ft.

Evaluation of QDT-3 results indicated that most small fragments appeared to come from interstices between the large fragments at the time they separated, with relatively small contributions from surface spalling and scabbing. Sizes of the small fragments were related to the rebar spacing and aggregate size. As an upper bound for the scaling of small fragments, it was estimated that, due to the impact of strain rate scaling, the number of fragments, N_o, observed for QDT-3 may be doubled with geometric scaling of each fragment dimension by a factor of 4.

QUANTITY-DISTANCE EVALUATION

Airblast

Results of the data analyses indicate that cube root scaling for airblast effects is readily applicable over the domain of the 1/10-scale and 1/4-scale experiments. The analytical predictions for the QDT-3 test were in agreement with the experimental results, with the associated computer model inherently reflecting cube root scaling for events of any scale magnitude. As far as can be judged from analytical and experimental results of the present study, it appears reasonable to conclude that the cube root law would be applicable for scaling of the data from the small scale tests to a full-scale event. The ground range to 1 psi for QDT-3 was 270 feet. It is, therefore, estimated that the quantity-distance for airblast overpressure would be 4 x 270 feet or 1080 feet for a full-scale explosion.

The predicted airblast pressure distribution was based on a closure-off analysis whereas QDT-3 was a closure-on experiment. The good agreement between analytical and test data appears to indicate a high probability that the presence or lack of the closure would yield similar airblast results for a full-scale event. It appears reasonable to conclude that the major causes for the lower ground ranges of the present study, as compared to early estimates, may be attributed to the energy loss to the flexible walls and surrounding medium, and to the reduction in early gas pressures by expansion into the LER cavity at the top of the silo launch tube.

Structural Debris

Scaling of the QDT-3 data for the S, NE, and NW radials by the statistical simulation method is represented by the plot of Figure 12(a). For a constant value of N_o, the full-scale range to a density of 1 per 600 sq ft is estimated as 812 feet (1/4-scale range)

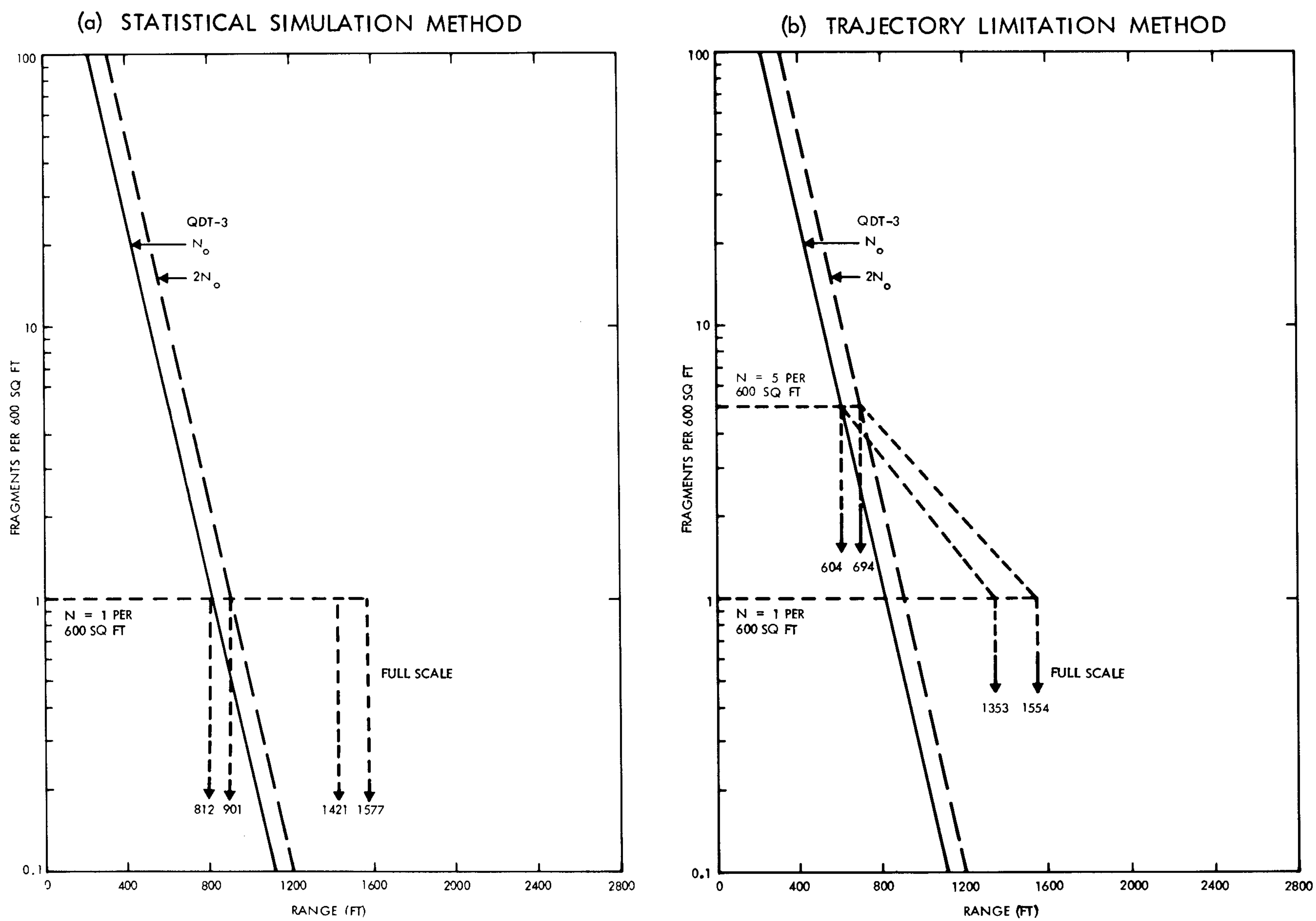


Figure 12. Debris Density Scaling for Data on S, NE, and NW Radials

multiplied by 1.75 resulting in a value of 1421 feet. As an upper bound, the full-scale range corresponding to a total fragment number of 2 N_o is 901 feet multiplied by 1.75 or 1577 feet.

A similar evaluation based on the trajectory limitation method is shown by the plot of Figure 12(b). For a fragment total of N_o, the 1/4-scale range for a density of 5 per 600 sq ft is 604 feet, so that the full-scale range to a density of 1 per 600 sq ft is, therefore, 604 x 2.24 = 1353 feet. For the case of 2 N_o, the full-scale range is 694 x 2.24 = 1554 feet.

The preceding results correspond to scaling of the QDT-3 data on the basis of the debris distribution for the S, NE, and NW radials. The same set of calculations was performed for the data based only on the debris distribution for the NW radial as a means of establishing upper limits to the full-scale ranges.

A summary of the scaling evaluations is presented in Table 4. It is recognized that there are various uncertainties associated with each full-scale range in addition to relative degrees of conservatism. It appears reasonable to assume that the average of all of the values, including the highly conservative, represents an upper bound of the required quantity-distance estimate. This average value, as given in Table 4, is 1567 feet.

Table 4. Full-Scale Quantity-Distance Estimates for Structural Debris

Debris Scaling Method	QDT-3 Radials	Total Fragment Number	Fragments per 600 ft^2	QDT-3 Range (ft)	Scale Factor	Full Scale Range (ft)
Statistical Simulation	S, NE, NW	N_o	1	812	1.75	1421
		$2N_o$	1	901	1.75	1577
	NW	N_o	1	896	1.75	1568
		$2N_o$	1	977	1.75	1710
Trajectory Limitation	S, NE, NW	N_o	5	604	2.24	1353
		$2N_o$	5	694	2.24	1554
	NW	N_o	5	706	2.24	1581
		$2N_o$	5	790	2.24	1770
Average						1567

SUMMARY AND CONCLUSIONS

Results of the study are briefly summarized as follows:

- Airblast

  1) The airblast data for the 1/10-scale and 1/4-scale tests verified applicability of cube root scaling.

  2) Excellent agreement between test data and predictions for the calibration shot validated the reliability of the airblast measurements.

  3) Analytical predictions for the 1/4-scale test were in agreement with test data.

  4) The ground range to a peak pressure level of 1 psi for the 1/4-scale test was determined to be 270 feet with a corresponding full-scale value estimated as 1080 feet.

- Soil Ejecta

  1) The ejecta distribution for the 1/4-scale test extended out to relatively limited ranges.

  2) The impact of ejecta on quantity-distance considerations was considered to be negligible.

- Structural Debris

  1) There was good correlation between predictions of structural fragmentation and test results.

  2) Geometric scaling of fragment dimensions was considered applicable to a full-scale event.

  3) An increase in total fragment number by a factor of two was estimated as an upper limit for a full-scale explosion.

  4) An upper bound of the required quantity-distance was determined to be 1567 feet.

It is readily apparent that structural debris is the governing hazard as related to determining quantity-distance criteria. Based on the analytical and experimental results of the present study, it is concluded that the adequacy of 1750 feet for the quantity-distance for the Peacekeeper system has been verified.

REFERENCES

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2. Sussholz, B., "Peacekeeper Quantity-Distance Verification Program," BMO-TR-84-17, TRW Defense Systems Group, Redondo Beach, CA, June 1984.

3. Ward, J. M., "Distant Runner - Debris Recovery and Analysis Program for Events 4 and 5, Naval Surface Weapons Center, White Oak Laboratory, Silver Spring, Maryland, April 1982.

ADDENDUM

During a presentation to the Department of Defense Explosives Safety Board (DDESB) in July 1984 regarding results of the Peacekeeper Quality-Distance Verification Program, an interest was expressed in determining the sensitivity of the Q-D estimates to variations in the drag coefficient parameter from 0.5 to 1.0. An evaluation was performed indicating that the average full-scale range corresponding to a drag coefficient of 1.0 was 1644 feet, which is a factor of only 4.9% greater than the value of 1567 feet established for a drag coefficient of 0.50. Details of the analyses are presented in the following discussion.

A comparison is shown in Table A-1 of the upper bound range multiplication factors that were developed on the basis of the trajectory limitation approach for drag coefficients of 0.5 and 1.0. The average value of 2.29 determined for a C_D of 1.0 is a factor of 2.2% greater than the value of 2.24 associated with a C_D of 0.50.

Table A-1. Upper Bound Range Multiplication Factors for C_D = 0.5 and 1.0

Fragment Length (in.)		R_{4L}/R_L	
1/4 Scale	Full Scale	C_D = 0.5	C_D = 1.0
0.50	2	2.36	2.41
0.75	3	2.24	2.28
1.00	4	2.22	2.26
1.50	6	2.21	2.25
2.00	8	2.18	2.23
	Average	2.24	2.29

A calculation was performed for Case 13 based on the statistical simulation technique with the following assumptions: (a) skewed distribution for launch velocities and angles, (b) QDT-3 shape factors, (c) fragment size gradient of 2/3, and (d) drag coefficient

of 1.0. These parameters are similar to those of Case 11 in the study except that the drag coefficient is 1.0 instead of 0.5. Results of the analysis for Case 13 are presented in Table A-2 in comparison with the associated data for the other 12 cases.

The debris scaling factor based on the ratio of full-scale range to 1/4-scale range at a density of 1 per 600 sq ft was evaluated to be 1.90 for Case 13 as compared to 1.75 for Case 11, or an enhancement by about 8.6% for an increase in C_D from 0.5 to 1.0.

Tables A-3 and A-4 present Q-D estimates based on C_D values of 0.5 and 1.0, respectively. The average full-scale range for $C_D = 0.5$ was determined to be 1567 feet, whereas the corresponding value for $C_D = 1.0$ was evaluated as 1644 feet. The difference of 4.9% indicates that Q-D estimates are relatively insensitive to drag coefficient parameters.

Table A-2. Comparison of Debris Scaling Evaluations by Statistical Simulation Method

Case	Launch V_o and θ_o Spectrum	Drag Coefficient	Number Gradient	Scaling Approach A			Scaling Approach B				Scaling Approach C				
				$R_{1/4}$ for 1/600 ft^2 (ft)	$(R_{FS})_1$ for 1/600 ft^2 (ft)	$\frac{(R_{FS})_1}{R_{1/4}}$	Scale Factor λ	λ^2	$R_{1/4}$ for λ^2/600 ft^2 (ft)	$(R_{FS})_1$ for 1/600 ft^2 (ft)	Scale Factor λ	λ^2	$(R_{1/4})_4$ for 16/600 ft^2 (ft)	$(R_{FS})_4$ for 1/600 ft^2 (ft)	$\frac{(R_{FS})_4}{(R_{FS})_1}$
1*	Uniform	1/2	1/2	848	1644	1.93	2.72	7.4	604	1644	4	16	512	2048	1.24
2	Uniform	1/2	2/3	1020	1999	1.96	2.88	8.3	694	1999	4	16	593	2322	1.19
3	Uniform	1/2	3/8	732	1446	1.98	2.74	7.5	528	1446	4	16	453	1812	1.25
4	Skewed	1/2	1/2	773	1572	2.03	2.88	8.3	546	1572	4	16	475	1900	1.21
5	Uniform	1	1/2	553	1249	2.26	3.11	9.7	402	1249	4	16	367	1468	1.18
6	Skewed	1	1/2	516	1150	2.23	3.11	9.7	370	1150	4	16	336	1340	1.16
7	Uniform; Scaling 2:1	1/2	1/2	848	1704	2.01	2.88	8.3	591	1704	4	16	512	2048	1.20
8	Uniform; $2N_o$	1/2	1/2	932	1889	2.03	2.76	7.6	684	1889	4	16	596	2348	1.26
9	Uniform; $1/2N_o$	1/2	1/2	764	1398	1.83	2.64	7.0	530	1398	4	16	427	1708	1.22
	Average					2.03	2.86	8.2							1.21
10**	Skewed	1/2	1/2	670	1159	1.73	2.10	4.4	552	1159	4	16	450	1800	1.55
11	Skewed	1/2	2/3	750	1310	1.75	2.12	4.5	616	1310	4	16	504	2016	1.54
12	Uniform	1/2	2/3	712	1140	1.60	2.14	4.6	531	1140	4	16	384	1536	1.35
13	Skewed	1	2/3	456	865	1.90	2.21	4.9	391	865	4	16	343	1373	1.59

*Cases 1-9: Distant Runner shape factors - pretest calculations
**Cases 10-13: QDT-3 shape factors - post-test calculations

Table A-3. Full-Scale Quantity-Distance Estimates Based on a Drag Coefficient of 0.5

Debris Scaling Method	QDT-3 Radials	Total Fragment Number	Fragments per 600 ft^2	QDT-3 Range (ft)	Scale Factor	Full Scale Range (ft)
Statistical Simulation	S, NE, NW	N_o	1	812	1.75	1421
		$2N_o$	1	901	1.75	1577
	NW	N_o	1	896	1.75	1568
		$2N_o$	1	977	1.75	1710
Trajectory Limitation	S, NE, NW	N_o	5	604	2.24	1353
		$2N_o$	5	694	2.24	1554
	NW	N_o	5	706	2.24	1581
		$2N_o$	5	790	2.24	1770
Average						1567

Table A-4. Full-Scale Quantity-Distance Estimates Based on a Drag Coefficient of 1.0

Debris Scaling Method	QDT-3 Radials	Total Fragment Number	Fragments per 600 ft^2	QDT-3 Range (ft)	Scale Factor	Full Scale Range (ft)
Statistical Simulation	S, NE, NW	N_o	1	812	1.90	1543
		$2N_o$	1	901	1.90	1712
	NW	N_o	1	896	1.90	1702
		$2N_o$	1	977	1.90	1856
Trajectory Limitation	S, NE, NW	N_o	5.24	598	2.29	1369
		$2N_o$	5.24	688	2.29	1575
	NW	N_o	5.24	701	2.29	1605
		$2N_o$	5.24	782	2.29	1791
Average						1644

SAFETY CONSIDERATIONS FOR RENOVATION AND DEMOLITION

OF

FACILITIES CONTAMINATED WITH CHEMICAL AGENTS

BY

THOMAS S. KARTACHAK

GEORGE E. COLLINS

Preface

This report was developed in support of the Chemical Research and Development Center (CRDC) Military Construction, Army (MCA) Program and the CRDC Minor Construction Program. Although it addresses many of the health and safety aspects of a safety program for renovation or demolition of facilities contaminated with chemical agent, this publication cannot be all encompassing. Supplementary and/or specific guidance is contained in the selected references.

1. Introduction. The requirements for developing and implementing a system safety program are contained in MIL STD 882B, System Safety Program Requirements, 30 Mar 1984. This system safety program was used to develop the safety requirements for renovation and demolition of facilities.

The principle objective of a safety program for renovation and demolition operations with facilities contaminated with chemical agent is to insure safety, consistent with mission requirements, is incorporated into the operations. All hazards that may be encountered during the operations must be identified, evaluated and eliminated or controlled to an acceptable level.

This report outlines the major health and safety considerations that must be addressed during the renovation or demolition of a chemical agent contaminated facility.

These safety provisions were developed by analyzing the renovation and demolition operations to identify potential hazardous conditions. Pertinent standards, specifications, regulations, training manuals, field manuals, and other related documents were reviewed to assist in specifying operational requirements. The general operational safety requirements were to:

a. Eliminate identified hazards.

b. Control or minimize the hazards to personnel, equipment, or facilities that cannot be avoided or eliminated.

c. Isolate hazardous substances and operations from other activities, personnel and areas.

d. Avoid undue exposure of personnel to physiological and psychological stresses which might cause error or mishap.

e. Consider alternate approaches to minimize hazards that cannot be eliminated. Such approaches include protective clothing, equipment and devices.

f. Design operation to minimize risk created by human error.

g. Include warnings and caution notes for hazardous operations and provide instructions and distinctive markings on hazardous components, equipment, or facilities for personnel protection when the hazard cannot be eliminated.

2. DISCUSSION.

2.1 Extent of Contamination

The areas of the facilities and pieces of equipment located in facilities that are potentially contaminated with chemical agent must be identified. Preliminary information on the extent and type of contaminant can be obtained from historical records of facility use. Atmospheric monitoring can be performed to confirm the presence or absence of chemical agent.

2.2 Hazards Information.

The hazards information on chemical agents that may be encountered when working in contaminated or potentially contaminated areas must be provided to the workers. Chemical agents are grouped according to their use, their physiological actions and their physical and chemical properties. Permissible Exposure Limits (PELs) and Time Weighted Averages (TWA) have been established for some chemical agents. Personnel working in these areas shall not intentionally be exposed to concentrations exceeding the time weighted averages.

2.3 Work Zones.

The cardinal principle to be observed in any location or operation involving toxic materials is to limit the exposure to a minimum number of personnel for a minimum time, to a minimum amount of the hazardous material consistent with safe and efficient operations.

Work zones and support areas should be established to contain contamination within the smallest area possible and to protect workers and other personnel from exposure to contaminants. Appropriate personal protective equipment shall be required for all persons for the area or zone in which he or she is working. These work areas must be clearly defined and access limited to only authorized personnel who have received appropriate safety training.

Contaminated areas and equipment (rooms, cubicles, hoods, ductwork) must be identified by a sufficient number of hazard signs or markings. The signs must indicate the presence of chemical agent and stipulate that entry into the structure or areas is restricted to authorized personnel. These signs/markings must be prominently placed on all structures, in all areas and on all equipment which is contaminated. These signs/markings must remain in place until complete decontamination has been certified.

2.4 Personnel Protective Practices.

A personnel protective practice training program for employees engaged in these operations must be established. All employees must receive training, prior to the beginning of these operations, in the following:

a. Information about the effects of the agents and recognition of exposure symptoms.

b. First-aid and self-aid procedures.

c. Hazards involved in the operation.

d. Emergency procedures.

e. Operating procedure to include safety requirements.

f. Personnel decontamination procedures.

All employees should also take part in an on-going program of instruction which will include:

a. Techniques of wearing, adjusting, and caring for the protective clothing.

b. Use of first aid equipment.

c. Recognition of signs and symptoms of agent exposure.

d. Cardiopulmonary resuscitation, first-aid and self-aid.

e. Emergency procedures.

f. Decontamination procedures.

2.5 Protective clothing.

If the chemical agent hazard in the facility cannot be eliminated, alternate approaches such as protective clothing and equipment may be used to minimize the hazards to personnel. The protective clothing selected must be capable of protecting personnel from chemical agent contamination which may be present in each area. Therefore, the type of protective clothing must be determined for each operation based on the hazards expected to be encountered.

The US Army Materiel Command (AMC) provides guidance in selecting the appropriate protective clothing in AMC Safety Regulations for the specific chemical agent. If military type classified protective clothing is selected to provide protection from chemical agent contamination, it must be worn, handled, decontaminated, laundered, inspected, maintained, tested, stored and issued in accordance with all regulations, technical manuals (TMs), and field manuals (FMs) and other related documents on the equipment. A separate area should be established where protective clothing will be laundered, inspected, tested and issued. Specific testing apparatus, such as the Q79A1 leak tester may be required to be used to leak test items of protective clothing.

If respiratory protection is required for certain operations, a program for selection, use, inspection, testing, and maintenance that complies with TB Med 502 must be established. This program must include:

a. Selection of the appropriate respirator for the conditions of employment,

b. Fitting and training the wearer in the use and care of the device and the means by which it gives protection,

c. Establishing a facility for the issue, testing, and organizational maintenance of serviceable respiratory protective equipment in accordance with the current supply and maintenance guidance for the equipment.

2.6 Workplace atmospheric monitoring.

A workplace atmospheric monitoring program to monitor worker exposure to potential chemical agent contamination must be established. A Quality

Control Program must also be established to ensure the results are accurate.

Where feasible, monitoring of work areas where unprotected personnel perform duties will be accomplished with equipment that has the capability to detect and alarm at low level concentrations (usually the TWA) of the chemical agent.

Detailed records of the results of monitoring in support of operations will be collected daily, and will be maintained as permanent files (40 years) at the installation. Monitoring records will be identified by date, time, type of agent, and physical location, and will also include a daily record of personnel entering the building/area.

2.7 Decontamination and Disposal.

All material demolished and removed must be decontaminated. Methods and levels of decontamination are contained in regulations, TMs and FMs depending on the chemical agent contamination present. Areas that are expected or known to be contaminated should be decontaminated, and certified by the user to the xxx level of decontamination.

Appropriate tests must be used to assign a level of decontamination. The levels of decontamination may be:

"X" - A single "X" indicates the level of decontamination is unknown or is contaminated to the extent that vapor concentrations from the contained item exceeds a certain concentration.

"XXX" - Three "X's" indicates that the item has been surface decontaminated by locally approved procedures, contained, and that appropriate tests or monitoring has verified that vapor concentrations above a certain concentration do not exist.

"XXXXX" - Five X's (5X) indicates that the item is clean and may be released from Government control without precaution and restriction. This level must be certified by the Commander's designated representative.

Specific forms and/or physical markings should be used to identify decontaminated equipment, materials and facilities.

Prior to release of contaminated facilities for non-related operations, the facilities must be certified to the 3X level of decontamination.

2.8 Medical and First-Aid Requirements.

Medical support including personnel, facilities, equipment and services for the treatment of chemical agent exposures must be provided. This medical support must include:

a. Preplacement, periodic, and termination medical evaluations for each person who is to work with chemical agent contaminated material and equipment. The scope of the medical examination, and frequency of periodic

tests, such as blood cholinesterase) are specified by the USA Health Services Command and the AMC Surgeon General.

b. Observation at the end of each working day of each person working in a chemical agent contaminated area, for evidence of possible exposure to chemical agent.

Emergency response equipment must be immediately available at the location where operations are conducted. This equipment should include:

a. a vehicle that can be used as an ambulance,

b. a communications system which can be used to summon aid,

c. appropriate decontamination materials,

d. a supply of clean water for decontamination purposes,

e. appropriate first aid equipment, instructions, and supplies.

All personnel engaged in these operations must be furnished a medical identification card (a bracelet is optional). Personnel may be requested to carry this information on their person during off-duty hours. A system must be established to ensure appropriate response during non-duty hours for emergency medical information, advice, or assistance.

2.9 Equipment and tools.

All tools and equipment used in disassembly, handling or disposal of chemical agent contaminated material must be identified by a permanent marking system that cannot be removed during chemical agent operations, decontamination, or maintenance. These items must be stored separately from tools that have not been used in chemical agent operations. These tools and equipment must not be released from Government control unless they are decontaminated to the 5X level.

Records must be maintained listing all equipment that was used in chemical agent operations and is placed on stand by status, removed, and saved for future operations, or is converted to use in other operations. These records must identify the contaminating agent(s), the decontamination process used, and the methods and results of analyses used to confirm the effectiveness of the decontamination.

2.10 Job Hazard Analysis.

A job hazard analysis should be conducted for all chemical agent operations and revised whenever there is a change in production, process or control measure. A written record of the job hazard analysis should be made and maintained as a permanent record. Results of the analysis should be used to develop the safety requirements for the operation.

2.11 Standing Operating Procedures.

Standing operating procedures (SOP) for operations with contaminated equipment and facilities must be developed, and approved by the Commanding Officer of the installation before operations begin. The SOP should include:

a. step-by-step instruction to perform the work,

b. safety requirements,

c. personal protective clothing and equipment,

d. personnel limits.

The SOP must be posted at the work site. No deviation from this procedure is permitted without approval of the Commanding Officer.

2.12 Hazardous Area Work Permits.

A hazardous area work permit system may be used to apply the health and safety controls for operations. This permit system can identify:

a. the nature of the operations,

b. the extent and location of the chemical agent contamination,

c. all applicable safeguards,

d. all medical/first aid requirements for the job, and,

e. the names of all medically cleared personnel who will be performing the operations.

2.13 Safety Inspection of Worksite.

The renovation and demolition operation worksite must be inspected at least annually. More frequent inspections should be made for operations involving special hazards. The Standard Army Safety and Occupational Health Inspection procedures, which were established by the Department of the Army, must be followed. These inspections must be conducted by qualified military or civilian safety and health professionals. Written reports of the results of these inspections, citing hazards, safety management deficiencies, and recommending corrective action(s) must be kept.

2.14 Accident Investigation and Reporting.

All accidents resulting in injury, occupational illness, or property damage must be investigated, analyzed, reported, and/or recorded.

Chemical accidents and incidents must be reported telephonically within three hours of detection. A follow-up electrically transmitted message must be sent no later than 24 hours after the accident or incident. The following information is required in this report:

Date and Time of Event,

Location,

Quantity and type of weapon(s) or container(s) and chemical agent(s),

Description of property damage and personnel casualties,

Type of carrier, if one is involved,

Type of operation,

Description of the event,

Whether a weapon or container burned, detonated (to what degree), or was exposed to fire,

Details of an existing chemical hazard or contamination, or explanation of circumstances/conditions requiring emergency disposal,

Condition of chemical weapon or container,

Whether a news release was given to the media,

Measures taken to ensure safety and security,

Any other pertinent information, including cause factors, if known, decision making process for determining the necessary corrective or emergency action, and any possible political implications,

Corrective actions recommended, or method of disposal and earliest date which disposal will be accomplished, if appropriate,

Assistance required.

3. CONCLUSION:

A project to renovate or demolish facilities contaminated with chemical agent must ensure that safety is incorporated into the operations. This report outlined these major health and safety considerations.

DEVELOPMENT OF NOVEL DECONTAMINATION TECHNIQUES FOR CHEMICAL AGENTS (GB, VX, HD), CONTAMINATED FACILITIES

Contract DAAK11-81-C-0101

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1.0 INTRODUCTION

One of the United States Army Toxic and Hazardous Materials Agency's (USATHAMA) mandates is to develop new, improved and cost effective procedures for the decontamination of facilities utilized for chemical warfare agent (GB, HD and VX) manufacturing, or testing. Facilities of concern include the contaminated buildings underground and above ground storage tanks, reaction vessels, sumps, piping and other operationally related structures.

1.1 Scope of Work

Facility decontamination involves decontamination of the exposed surfaces of the material as well as agent which has penetrated the surfaces into cracks, pores or crevices. The only currently approved method of decontaminating materials involves maintaining the materials at a temperature of 1000 F for a period of 15 minutes.* Materials exposed to such conditions are described as having been decontaminated to the 5X condition and are defined as

* DARCOM-R 385-102 "Safety Regulation for Chemical Agents GB and VX", May 15, 1981.
DARCOM-R 385-31 "Safety Regulations for Chemical Agents H, HD, and HT", April 1979.

suitable for unrestricted use by non-qualified government or private users. The expense and time required to accomplish such a decontamination scenario for useful buildings would be immense. As such, alternative novel decontamination concepts which would not require dismantling of a contaminated facility and which would result in a 5X decontamination status (or its equivalent) without incineration represents a potentially large cost savings to the Government.

1.2 The 5X "Dilemma"

A dilemma in the identification of any novel, non-incineration decontamination concept arises because of the fact that the desired level of decontamination specified is defined as the 5X condition. Since the 5X condition is an operational rather than an analytical definition, it does not provide a means to analytically evaluate the relative efficacy of novel decontamination concepts either in the preliminary screening or in subsequent laboratory testing. In fact, there apprears to be little experimental documentation that the 5X condition actually accomplishes total decontamination, although our study indicates that such a conclusion is appropriate at least in the case of surface decontamination. So that we might have a more tangible criterion upon which we could evaluate novel decontamination concepts, we elected (in agreement with USATHAMA) to define the reduction of contamination to a level below that detectable by state-of-the-art analytical techniques* as constituting a successful decontamination.

1.3 Program Outline

The program to develop novel decontamination concepts is divided into three phases.

- Phase 1. Identify, rank order and select concepts for laboratory evaluation (Completed).
- Phase 2. Experimentally validate selected concepts and recommend a concept(s) for field studies (In progress).
- Phase 3. Implement concept(s) on pilot-scale demonstration in the field (Future).

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* See Federal Register Vol. 45, No. 209, pg. 71304, para. 644.519.

The results from the first phase and progress made during the second phase are briefly discussed in the following sections.

2.0 PHASE 1

In Phase 1, ideas were systematically developed into concepts for decontaminating buildings and equipment. The 56 concepts, categorized into non-destructure thermal methods, chemical methods, extractive methods and abrasive removal methods, are listed in Table 1. These concepts were defined and evaluated in relation to the following criteria:

- Safety
- Damage to Building
- Penetration Depth
- Applicability to Complex Surfaces
- Operating Cost
- Capital Cost
- Waste Treatment/Recovery Cost
- Destruction Efficiency

The concepts were rank ordered and several of the most promising concepts were selected for a preliminary engineering/economic analysis. Finally, eight concepts were selected for further evaluation in Phase 2. These were:

- Hot Gases
- Freon 113 Vapor Circulation
- Steam
- Flashblast
- NH_3 Gas
- MEA
- OPAB
- NH_3/Steam

TABLE 1. CONCEPTS FOR AGENTS DECONTAMINATION

CHEMICAL

OCTYL PYRIDINIUM 4-ALDOXIME BROMIDE (OPAB)
DS2
CD-1
SUPERTROPICAL BLEACH (STB)
ALL PURPOSE DECONTAMINANT (APD)
MONOETHANOLAMINE
GAMMA RADIATION
NITRIC ACID
AMMONIUM HYDROXIDE
HYPOCHLORITES
DANC
GASEOUS AMINES
CHLORINE
STEAM
AMMONIA/STEAM
PERCHLORYL FLUORIDE
GERMAN EMULSION
HYDROXAMIC ACIDS
SODIUM HYDROXIDE SOLUTION
DIMETHYLSULFOXIDE
MACROCYCLIC ETHERS
PROPIONYL FLUORIDE
PHENOLS/CATECHOLS
CARBONATE/BICARBONATE SOLUTIONS
CHLORITE SOLUTIONS
CHLORINE DIOXIDE
NITROGEN TETROXIDE
BORON TRIFLUORIDE
OZONE
SULFUR DICHLORIDE
UV/OZONE
ULTRASONIC DECOMPOSITION
COPPER LIGANDS
VANADIUM CATALYZED HYDROLYSIS
ANTHRANILIC ACID-SILVER COMPLEXATION
MAGNESIUM HYDROXIDE IMPREGNATED ALUMINA
COMPLEXATION WITH MOLYBDENUM LIGAND
PERBORATES
MICROBIAL DEGRADATION
PERMANGANATE SOLUTIONS
ENZYME PROTEINS
SODIUM SULFIDE

PHYSICAL/EXTRACTION

SURFACTANTS
STRIPPABLE COATING
VAPOR CIRCULATION
SOLVENT CIRCULATION
SUPERCRITICAL FLUIDS
ULTRASONIC EXTRACTION

PHYSICAL/ABRASIVE

HYDROBLASTING
ACID ETCH
SANDBLASTING
DEMOLITION
VACU-BLASTING
CRYOGENICS
SCARIFICATION
ELECTROPOLISHING
DRILL AND SPALL

THERMAL

FLASHBLASTING
HOT PLASMA
MICROWAVE HEATING
FLAMING
HOT GASES
SOLVENT SOAK/BURN
INFRARED HEATING
CARBON DIOXIDE LASER
ELECTRICAL RESISTANCE CONTACT HEATING

3.0 PHASE 2

In Phase 2, which is ongoing, knowledge gaps relating to the application of the eight most promising concepts are being addressed through laboratory evaluation.

3.1 Preliminary Evaluation of Five Chemical Decontamination Concepts

A preliminary evaluation of the five chemical decontamination concepts (i.e., steam, NH_3, MEA, OPAB and NH_3/steam) was performed in laboratory glassware. The results, shown in Table 2, indicate that steam and OPAB were the most effective decontaminants and, as such, were selected for further evaluation in coupon decontamination tests. Products from the reactions are being characterized.

3.2 Coupon Decontamination Tests

Coupon decontamination tests involve decontamination of painted and unpainted mild steel and stainless steel coupons spiked with a known amount of GB, VX or HD. The tests were performed in a chamber which allowed containment of the coupons and sampling of the effluents during implementation of the decontamination treatment. Results of the tests using unpainted stainless steel coupons are shown in Table 3. The results indicate that the hot gas and steam concepts were effective in decontaminating the HD, GB and VX contaminated coupons to residual levels below the detectable limit. Although residual agent remained on the coupons following decontamination with OPAB, extrapolation of the results suggest that decontamination to below the detectable limit can be achieved if more OPAB is applied. Thus, the hot gas, OPAB and steam concepts were selected for further evaluation on painted stainless steel, painted and unpainted mild steel. Preliminary results of these tests suggest that the hot-gas and steam concepts were successful in decontamination of the coupons spiked with GB, HD or VX to below the detectable limit. Work is in progress in determining the decontamination effectiveness of OPAB.

TABLE 2. SUMMARY OF RESULTS FROM PRELIMINARY EVALUATION OF FIVE CHEMICAL AGENT DECONTAMINATION CONCEPTS

Chemical Decontamination Method	GB		HD		VX	
	Time (min)	Residual Agent[a] (percent)	Time (min)	Residual Agent (percent)	Time (min)	Residual Agent (percent)
Steam	120	BDL[b]	20	BDL	120	0.5
NH_3 Gas	60	1.4	60	90.3	60	14.2
NH_3/Steam	60	45.7	60	BDL	60	19.3
OPAB	1	BDL	360	BDL	240	BDL
50% MEA	1	BDL	240	BDL	1440	16.4
100% MEA	1	BDL	240	BDL	1440	54.0

a) Residual agent (%) $= \left(\frac{\text{Residual Agent (mg)}}{\text{Initial Agent (mg)}}\right) \times 100$

b) BDL = Below detectable limit.

TABLE 3. SUMMARY OF UNPAINTED STAINLESS STEEL COUPON DECONTAMINATION RESULTS FROM THE FIVE DECONTAMINATION CONCEPTS

Decontamination Method	Conditions	Residual Agent Remaining on Coupon following Decontamination[a] (Percent)		
		HD	GB	VX
Hot Gases	60 minutes at 150 C	BDL	BDL	BDL
Steam	HD 40 minutes at 100 C GB 60 minutes at 100 C VX 180 minutes at 100 C	BDL	BDL	BDL
Vapor Circulation	HD Heat up to 48C GB Heat up to 48C VX 2 hours at 48C	BDL	BDL	3.6
Flashblast	48 kw applied power	BDL	0.4	0.5
OPAB	Spray 10 times at 0.05 gal/sq.ft. coverage	0.3	BDL	0.4

(a) Residual agent (%) $= \left(\frac{\text{Residual Agent (mg)}}{\text{Initial Agent (mg)}}\right) \times 100$

(b) BDL = Below detectable limit.

3.3 Current Efforts

In addition to the OPAB decontamination tests, current efforts include determining the interaction between concrete and the agents. Because of its inherent basicity, concrete may cause decomposition of the agents. As such, contaminated unpainted concrete may not have to be decontaminated after an interval of time after the last exposure.

Also, an engineering/economic analysis of the application of the hot gas, steam and OPAB concepts to model structures representative of Army installations, is in progress. Based on the laboratory results and the engineering/economic analysis, a concept(s) will be selected for field evaluation in Phase 3.

4.0 PHASE 3

In Phase 3, the concept(s) selected from Phase 2 will be further developed and then implemented in pilot scale tests at a selected site. A contaminated room, for example, will be sampled, decontaminated and sampled again to determine the effectiveness of the concept. Key concerns in determining the effectiveness of the concept include:

- Sampling methodology
- Analytical methodology
- Validated verification of decontamination
- Level of contamination following treatment (i.e., below detectable limit vs. 5X)
- Data base requirements for full-scale implementation.

5.0 CONCLUSIONS

Novel decontamination techniques for facilities are being developed through laboratory and engineering evaluations. One or more concepts will be selected for pilot-scale testing at a field site.

DEVELOPMENT OF NOVEL DECONTAMINATION TECHNIQUES FOR EXPLOSIVE CONTAMINATED FACILITIES

Contract DAAK11-81-C-0101

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1.0 INTRODUCTION

One of the United States Army Toxic and Hazardous Materials Agency's (USATHAMA) mandates is to restore contaminated Army facilities which have been used for manufacturing, loading, packing and storing explosives so that these facilities can be removed or reclaimed for alternate use. Explosive contaminants of concern include TNT, 2,4-DNT, 2,6-DNT, HMX, RDX, Tetryl and other explosives manufactured and used by the Army. Facilities to be addressed include the building production equipment, above and underground storage tanks, wastewater/sludge sumps ventilation ducts, conduits and related explosive/munition production. The decontamination involves the removal of explosives from exposed surfaces of the materials as well as explosives that have penetrated porous media, cracks, and expansion joints. Site inspections have been performed and the contaminated structures include a wide range of concrete and wood frame structures.

1.1 The 5X Dilemma

The desired level of decontamination to be achieved is "5X" which is defined as "permitting unrestricted use of the previously contaminated site or material". The 5X level of decontamination is also defined as being

exposed to a temperature of 1000 F for 15 minutes. Since the 5X condition has an operational rather than an analytical definition, it does not provide a means to evaluate the relative efficacy of novel decontamination concepts. The only method currently being used to decontaminate building facilities is to torch (or flame) structural components in order to burn the explosive materials. However, no experimental documentation exists that indicates that flaming actually accomplishes total decontamination, although our study indicates that this conclusion is warranted in the case of surface decontamination.

1.2 Program Outline

The decontamination of buildings by flaming is only partially effective and is a very expensive technique. Thus, the objective of this program was to define and evaluate a novel decontamination method which would achieve the 5X criteria.

To implement this objective the program was divided into three phases:

- Phase 1. Identify, rank order, and select novel decontamination and inerting concepts for laboratory evaluations (Completed)
- Phase 2. Experimentally validate selected concepts and recommend a concept(s) for field study (In Progress).
- Phase 3. Implement concept(s) on pilot-scale decontamination process in the field. (Future)

2.0 PHASE 1 STUDIES

The first activity performed was the identification of potential decontamination and inerting methods. This was performed by performing the following tasks:

- Literature reviews
- Idea generation sessions

- Compilation of a computerized data base cataloging, storage and retrieval system.

These tasks resulted in the generation of potential decontamination concepts which are listed in Table 1 in the general categories of thermal, extractive, abrasive, chemical and inerting methods.

All concepts were evaluated by applying the following evaluation criteria: safety, damage to building, penetration depth, applicability to complex surfaces, operating costs, capital costs, and waste treatment/recovery costs. Further criteria which were utilized to chemical decontamination concepts were mass transfer and destruction efficiency ratings.

Those concepts which were selected for evaluation in Phase 2 studies are shown in Table 2.

3.0 PHASE 2 STUDIES

3.1 Enhanced Aqueous Solubilization of Explosives

Each of the three chemical concepts that were tested in these studies are compatible with and typically performed in aqueous based solvent systems. However, each of the six target explosives have very low solubility (about 0.01 percent or lower) in water. Those additives which were screened for their potential enhancement of the aqueous solubilities of explosvies included the following materials:

- Cosolvents: dimethylsulfoxide (DMSO), dimethylformamide (DMF), and acetone
- Surfactants: nonionic, cationic, anionic, and speciality surfactants
- Complexing Agents: diethanolamine and 4-hydroxyethylpiperazine

The aqueous cosolvents DMSO and DMF at concentrations of 30 percent or higher were judged most suitable for use as decontamination or extraction solvent systems.

TABLE 1. CONCEPTS EVALUATED IN PHASE I

Thermal	Abrasive
Hot Gases	Vacu-Blast
Radiant (Infrared) Heating	Hydroblasting
Flaming	Acid Etch/Neutralization
Microwaves	Sandblasting
Burning to Ground	Scarification
Flashblasting	Demolition
Electrical Resistance Contact Heating	Cryogenics
Solvent Soak/Controlled Burning	Ultrasonic Extraction
CO_2 Laser	Electropolishing
Hot Plasma	Drill and Spall

Extraction	Chemical
Steam Cleaning - External	Radical Initiated Decomposition
Surfactants	Base Initiated Decomposition
Strippable Coating	Reduction with Sodium Borohydride
Vapor Phase Solvent Extraction	Reductive Cleavage
Steam Cleaning - Manual	Microbial Degradation
Solvent Circulation (FREON)	DS2 Decomposition
Supercritical Fluids	Gamma Radiation
	Sulfur Based Reduction
	Reactive Amines
	Ultraviolet Light/Hydrogen Peroxide
	Molten Reactant Systems
	Active Metals and Acids
	Nucleophilic Displacement
	Ozone Oxidation
	Ascorbate Reduction
	Solid State Hydrogen

	Inerting
	Inerting by Solubilization
	Inerting by Denitration
	Formation of Water Soluble Derivatives
	Desensitization by Water
	Desensitization by Steaming
	Desensitization with Reductants
	Desensitization with Stabilizer Coatings
	Decomposition with Reactive Amines

TABLE 2. SELECTED DECONTAMINATION CONCEPTS

Decontamination		
Thermal	Extraction	Chemical
Hot Gases	Vapor Condensation	Radical Initiated
	Solvent Extraction	Base Initiated
		Reduction (Sulfur based)

Explosives Inerting
Solubilization
Water Treatment

3.2 Prescreening of Chemical Decontamination Concepts

The decontamination effectiveness of solutions of sodium hydroxide, sodium sulfide, sodium disulfide, and Fenton's Reagent (catalyzed oxidation) towards explosives in aqueous DMSO and DMF solutions were determined. The variables studied with 2,4-DNT, TNT and RDX were water to solvent ratio, temperature and reagent concentrations. Preliminary product identification studies were performed by using gas chromatography coupled with mass spectroscopy (GC/MS). Sodium sulfide was the most effective decontaminant for all three explosives but was rejected because of the toxic nature of the reaction products (2,4-diamino-6-nitrotoluene from TNT; 2,4-diaminotoluene and nitro-hydroxylaminotoluene from 2,4-DNT; and N-nitro-N',N"-bis(hydroxylamino) hexahydrotriazine from RDX).

The most acceptable chemical decontamination concept for explosives was judged to be solutions of sodium hydroxide in aqueous DMSO (30 or 75 percent DMSO). Preliminary product analysis by GC/MS studies indicated that the major type of products from the decontamination of TNT and 2,4-DNT with sodium hydroxide resulted from the displacement of nitro groups by hydroxide or DMSO anions, the oxidation of methyl groups to carboxylate groups and the dimerization (and subsequent oxidation) to dibenzyl and stilbene derivatives. The major products of RDX and sodium hydroxide are volatile gases and inorganic ions but there was evidence of minor yields of RDX structural isomers.

It should be stressed that structural assignments based on GC/MS analysis are speculative in nature and do not confirm the structure of a compound. Many GC peaks were not identified. Any polymeric material (which has been reported from the reaction between TNT and sodium hydroxide) or other non-volatile products would not be detected by the GC/MS method. Furthermore, under the GC/MS conditions employed, some products may undergo thermal decomposition. Therefore, further analytical efforts are required to confirm the nature of these decontamination products.

3.3 Stainless Steel and Concrete Decontamination Results

3.3.1 Analytical Recoveries

Test results indicate that consistently high recovery of explosives can be obtained from stainless steel. However the recovery from concrete is inconsistent and dependent upon the initial explosives concentrations. This interference may be due to a combination of mass transfer and complexation effects as well as the induction of chemical reactions. To confirm adequate removal of explosives from concrete surfaces, a more detailed study of this phenomenon is required.

3.3.2 Hot Gases

Tests have indicated that elevating the temperature of stainless steel, mild steel, and concrete surfaces (both painted and unpainted) to 500 F and maintaining that temperature for 1 hour will remove greater than 99.9 percent of any of the six explosives from all six surfaces which were contaminated. This removal occurs through a combination of volatilization and decomposition pathways.

3.3.3 Chemical Concepts

The results of the solution chemistry studies have been successfully translated to building materials. Decontamination of stainless steel and concrete coupons has been effected by spraying them with 0.1N sodium hydroxide aqueous DMSO solutions.

3.4 FUTURE PHASE 2 EFFORTS

3.4.1 Combination of Chemical And Thermal Methods

Pretreatment of explosives spiked coupons with sodium hydroxide solutions (in aqueous DMSO) will be studied to determine if thermal decontamination of explosives will be aided by combining these two approaches.

3.4.2 Engineering Analysis

The results of the Phase I site survey and the experimental sub-tasks of Phase II will be incorporated into an engineering/economic analysis of the most promising candidate concepts. This analysis will be the basis for the final recommendations of concepts to be pursued in Phase 3.

4.0 PHASE 3

In Phase 3, the concept(s) selected from Phase 2 will be implemented in pilot scale tests at a field site. Contaminated rooms will be sampled, decontaminated and sampled again to determine the effectiveness of the concept. Key concerns in determining the effectiveness of the concept include:

- Sampling methodology
- Analytical methodology
- Validate verification of decontamination
- Level of contamination following treatment (i.e., below detectable limit vs. 5X)
- Data base requirements for full-scale implementation.

5.0 CONCLUSIONS

Novel decontamination techniques for facilities are being developed through laboratory and engineering evaluations. A concept(s) will be selected for pilot-scale testing at a field site.

ROYAL ORDNANCE FACTORIES - UK

DECOMTAMINATION OF EXPLOSIVES BUILDINGS AND PLANT AT ROF BRIDGWATER

Paper Presented by

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TWENTY FIRST DoD EXPLOSIVES SAFETY SEMINAR

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INTRODUCTION

ROF Bridgwater is an explosives manufacturing plant dedicated to the production of high explosives and composite propellants.

This paper outlines the systematic approach which is followed by ROF Bridgwater when major work involving the demolition of building structures and floors, or the repair of large items of equipment, takes place in areas where explosives have been manufactured or handled. Some examples of special techniques which have been used are also described in Annexes 'A', 'B' and 'C'.

The procedures consist essentially of 6 steps:

1. Acquiring preliminary information about the area where the work is to be done.

2. Conducting a work survey.

3. Deciding what preliminary precautions are required.

4. Deciding what precautions must be taken whilst the work is in progress.

5. Preparing the paperwork.

6. Doing the work and recording how it was done.

1. Preliminary Information

The previous history of production work carried out in the area is researched as far as possible so that the nature of potential hazards can be adequately determined. For example, a number of buildings on the Composite Propellant Section were originally used for tetryl manufacture and this explosive still manifests itself today even though some 40 years have passed since production ceased. Explosives made nowadays at Bridgwater include RDX, HMX, TNT, HNS and compositions involving some or all of these materials.

From this review of the previous history of the building the possible explosive hazards which might be encountered can be assessed and listed.

2. Work Survey

A thorough survey is made of the area where the work is to be done. This is carried out by the Head of Section in conjunction with representatives from the Engineering and Safety departments and any other personnel he judges can contribute suitable expertise relating to the job or area in question.

The main purpose of the survey is to examine the area in order to decide exactly how the work is to be done, who is to do it and what safety features must be incorporated. Matters such as remote control of certain operations or the use of other special techniques are considered at this stage.

If production operations have been performed under wet conditions, the most likely areas where explosives could have accumulated would be at or near floor level. Drains and gullies are examined very closely and particular note is taken whenever faults such as cracks in brick, mortar, tiles or asphalted areas are evident.

In 'dry' buildings, particular attention is paid to the possibility of explosive dust accumulations. Meticulous examination of all crevices, cracks, girders, stairways and ledges is made at all levels within the building, from floor to ceiling.

3. Preliminary Precautions

In the light of the information obtained from the previous history review and the work survey, the Head of Section then decides what preliminary precautions must be taken.

These might include:

a. Thorough cleaning by water and/or steaming, with scrubbing, followed by close inspection by a chemist. The entire building and equipment should be scrupulously checked for freedom from visible signs of explosive.

b. Chemical, thermal or other treatment. For example, arrangements might be made to flood the area to be worked on for some hours beforehand using sandbags or other devices to retain the water.

c. Testing for the presence of explosives. This may be done on site, or samples and swabs can be checked in the laboratory.

d. The use of compatible paint strippers. Structures which have been painted merit special attention, particularly where it can be seen that nuts and bolts have been painted over.

When considering these matters, the Head of Section may wish to seek advice or information from people who have previously dealt with similar situations, either at Bridgwater or elsewhere. He could make use of library facilities to consult reports covering demolition and decontamination procedures. He might also consider whether there may be a case for heat treatment in situ - an example of this will be given later.

4. Precautions to be Taken Whilst Work is in Progress

Particular attention is paid to the supervision and personal protection of those doing the work.

The concept of the stand-by or stand-over is used at Bridgwater. When a person is instructed to stand-by, he is required to be present in the building at all times the work is proceeding. To stand-over means that the job demands especially close attention and that there are no circumstances in which it can be left at any time while work is in progress. A person can stand-over only one job at a time.

A production worker who is appointed to stand-by or over work must have satisfactorily completed a formal training course. On each occasion that he is selected to act as a stand-by he is issued with written general instructions defining his responsibilities. He is also given in writing any instructions specific to the job in hand. He must not permit work to start unless a fully authorised precautions certificate is present in the work areas. He must ensure that all tradesmen, contractors and other personnel involved are fully aware of the precautions stipulated on the certificate and that these precautions are fully observed at all times. He also has full authority to stop the work if at any time he is not satisfied that it can proceed safely.

Heads of Section must consider carefully the level of stand-by appointed in relation to the work to be done. For work involving major demolition operations it will almost certainly be necessary to appoint a Foreman or Chemist to stand-by, or even stand-over, certain activities.

The protective clothing and equipment to be worn, including boots, goggles and visor, helmet, gloves, masks, ear defenders etc, are detailed precisely. If there is considered to be any danger of flying masonry becoming a hazard the wearing of additional body protection such as a flak-jacket is specified and complete protection of the head and eyes will be mandatory. Wherever possible, protective barriers are also employed. The stand-by must wear the same level of protection specified for the personnel actually carrying out the work.

The number of people present in the work area is kept to an absolute minimum at all times. No other work of any sort is permitted to take place when demolition is in progress.

Whenever possible non-ferrous tools are used. Ferrous tools are permitted only if absolutely essential and their use is strictly controlled.

All items, structures and materials within areas which are concerned in the manufacture or handling of explosives are considered to be contaminated until proved otherwise. (Proved means that the items have been raised to a temperature in excess of that necessary to ensure complete destruction of the explosive concerned). This assumption is made no matter how thorough the cleaning has been and even if negative results have been obtained on samples or swabs tested in the laboratory. Under these circumstances whenever drills, chisels or similar tools are being used a continuous stream of water is directed on to the area where the tool is being applied. It is NOT considered sufficient simply to wet the area prior to work commencing or to state on the precautions certificate that running water is to be at hand - the work area must be continuously soaked.

Consideration must be given to carrying out demolition work in stages. A sequence such as cleaning-inspection-testing-part demolition-further cleaning-inspection-testing-further part demolition may well be appropriate.

The use of paint strippers has been mentioned previously, particularly on nuts and bolts which have been painted. Threaded areas are always treated with caution and subjected to thorough cleansing. When undoing nuts and bolts the use of excessive force is avoided and such work is always done under running water.

The adoption of good-housekeeping procedures with frequent removal of rubble away from the work area is always highly desirable. Debris must be considered as contaminated with explosive and arrangements are made to treat it on an open fire.

5. Paperwork

Precautions certificates, special tool passes, fire permits and other necessary paperwork are prepared, authorised and displayed in accordance with the Director's instructions. Particular care is taken to ensure that the work to be done is defined clearly and precisely and that the precautions stipulated are comprehensive and unambiguous.

6. Record of Details for Future Reference

A record is kept of procedural details of major demolition work with particular emphasis being given to the precautionary measures adopted. Wherever possible, photographs are included in the record. This information is published as a Bridgwater Technical Note and thus becomes available for reference by those who will be faced with similar work in the future. All sections retain for immediate consultation a loose leaf folder containing such reports.

Summary

Guidance notes detailing the procedures given in this paper are issued to all Heads of Section who may have to deal with major structural change in explosive buildings. The point is stressed, however, that each case will have its own special features and must be assessed on its own merits. For work to proceed safety constant vigilance and attention to detail must be exercised at all times.

ANNEX 'A'

EXPLOSIVE DEMOLITION TECHNIQUES

1. Introduction

In early 1983, during the demolition by conventional means of a glazed brick partition wall in a process building, a small detonation occurred injuring a contractor. The building had been used for many years as an RDX boiling, oiling and waxing house and, although the surface of the wall had been cleaned, checked and wetted, it is suspected that a small amount of RDX had penetrated the mortar between the bricks.

It was, therefore, decided to find out whether the demolition of the wall could be completed using explosives engineering methods. The Royal Armament Research and Development Establishment was asked for advice and their Explosives Ordnance Branch visited the Factory. They reported that explosive demolition was a suitable method to complete the work and they agreed to undertake it and in addition to train a number of the Bridgwater staff in the technique.

2. Preparation on Site

The remains of the partition wall were thoroughly hosed and then submerged in water held by sand-bags for 48 hours. The wall was of single thickness of glazed brick and extended 4½ bricks deep into the building, being 2 bricks high for half its length and single brick high for the remainder. 3 samples of mortar scrapings were taken from exposed surfaces and these were checked in the laboratory for RDX content - only a minute trace was indicated (Diagram 1).

The following precautions were taken to prevent extraneous damage:

a. To prevent damage from propelled debris a barricade of sand-bags was positioned around the remains of the partition wall.

b. Adjacent surfaces were protected from surface damage by covering with a double layer of hardboard.

c. All windows and doors were opened to reduce over-pressure. Panes of glass from a window immediately above the work site were removed.

d. Consideration was also given to removing some light fittings but it was finally decided to leave them. The nearest was 10 metres from the work site.

3. Explosive Engineering Procedures

3.1 Safety Procedure

a. The number of persons directly involved in the charge laying operation was kept to a minimum.

b. A prohibited area within 80 metres of the work site was designated. Security of this area was maintained by the Factory Fire Brigade.

c. The firing post was situated about 75 metres from the work site. The Firing Officer was solely in charge of operations.

d. Factory personnel were warned generally of explosions within the factory due to demolition work by announcements over the public address system. Additionally, before each individual firing a warning in the immediate work area was given by sounding the 2-tone siren of the Fire Brigade control vehicle stationed on the prohibited area perimeter.

3.2 Charges, Detonators and Firing System

The charges used were made up from ⅛" thick strips of SX2 cut from sheets made in the factory. The strips were laid on ⅝" aluminium angle in the general configuration shown in Diagram 2. The individual weights and length of charge varied according to the break-up of brickwork the Firing Officer considered it was advisable to produce at each firing.

The detonator used for each charge was on L2A1. Generally this was placed on the apex of the charge and held in position by a plastic top hat device shown in Diagram 2.

Firing was carried out using 'Shrike' electronic ignition equipment sited 75 metres from the firing area and connected to the detonator by firing cable.

3.3 Method of Laying Charges

Charges were laid by the Firing Officer where required to give the desired effect. Direct contact with the brickwork or indirect contact using a wooden stand-off were utilised according to circumstances. The charge was attached to the firing site by adhesive tape.

3.4 Demolition of Partition Wall

The requirement was to remove the remains of the partition wall and provide a rebate of about 25 mm below the floor surface. The method employed was to use a number of small charges and remove the wall incrementally. Small charges were used to avoid over-pressure in the building.

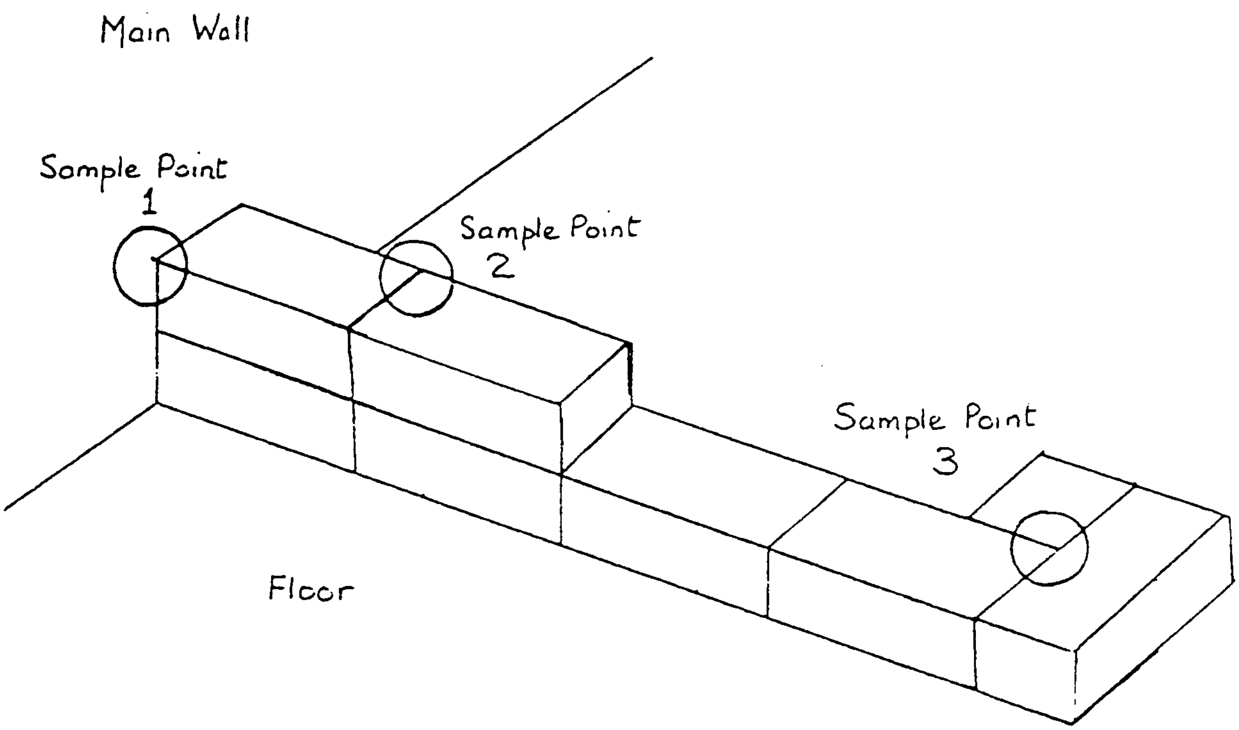
Debris was retained by the sand-bag enclosure, although a small amount of dust and small fragments were noted up to about 8 metres from the work site. After each firing, debris was removed and the area was brushed and hosed. A sample taken after the first firing was checked for RDX content - a figure of less than 0.01% RDX was reported. While removing portions of brick the charge was generally in direct contact; when providing the rebate into the floor the charge was stood off using wooden blocks. A total of 15 charges was used to complete the work.

4. Assessment of Finished Results

The work was satisfactorily completed. It was noted that following the firing of one incremental charge during the cutting of the recess into the flooring, the Firing Officer reported that the damage to the concrete sub-strata was probably caused by shock waves from earlier firings but it does not rule out the possibility that additional trapped explosives had been detonated during that firing.

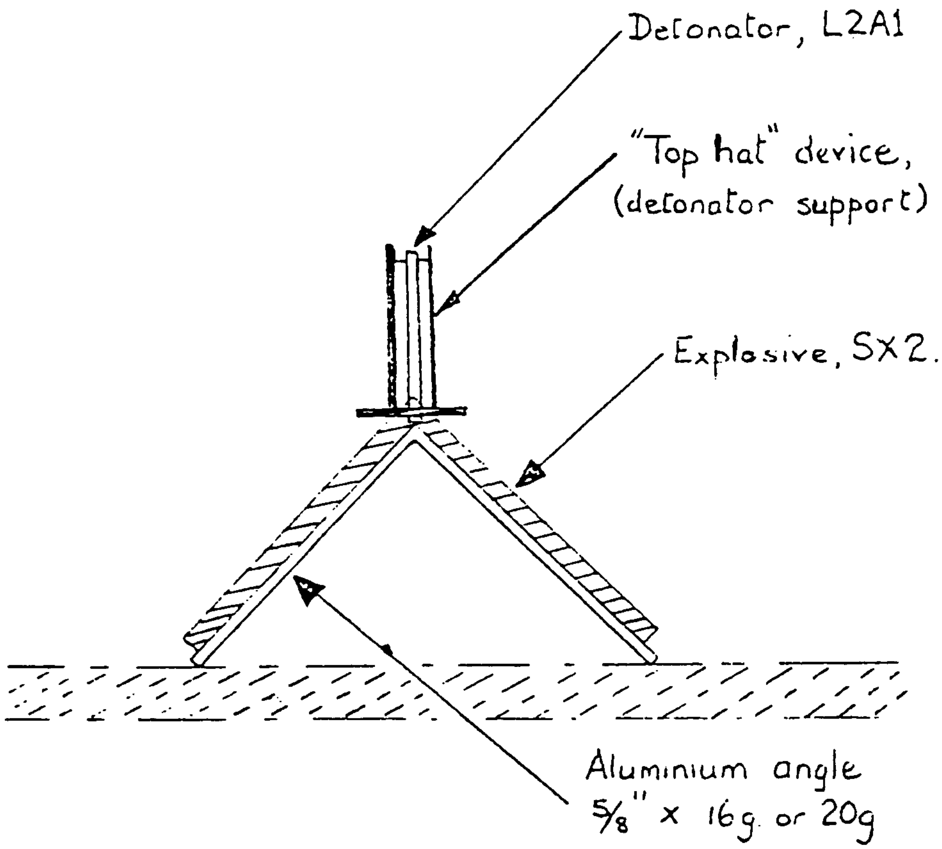
5. Acknowledgement

Grateful acknowledgement is made to RARDE EM1/EOD Branch for their technical and practical expertise in carrying out this work.



Remains of partition wall before final demolition showing Sample Points

ANNEX A - DIAGRAM 1



Cross section of Explosive Charge and Detonator.

ANNEX A - DIAGRAM 2

ANNEX 'B'

HEAT TREATMENT OF THE TNT NITRATION UNIT PRIOR TO REPAIRS INVOLVING GRINDING AND WELDING

1. Introduction

After completion of a production run in April 1982, inspection of the TNT Nitration Unit revealed a hole at one end of the vessel and also defects in some welds in the area.

Because of the large size of this unit (it measures 9.6 metres long x 1.3 metres wide x 1.4 metres high and weighs about 3.75 tonnes) its removal from the building for heat treatment in the proving oven (the normal Bridgwater procedure) was considered impracticable. It was, therefore, decided that heat treatment of the relevant areas of the unit in situ was the only alternative. At first it was envisaged that this would be achieved by heating all welds in the area to be repaired to a temperature of at least 400°C (indicated by temperature sensitive paint) using a remotely operated oxy-acetylene torch.

It soom became apparent, however, that there would be major problems in this approach - possible local overheating of welds leading to structural changes in the steel and also the drawback that only the welds (a small proportion of the total compartment area) would have been proved. A better method of heat treatment was sought.

In 1980 a firm had been employed to stress relieve a welding repair to the manhole of an ammonia storage vessel by subjecting it to an accurately programmed heating/cooling cycle with the aid of electrically heated pads. The firm was contacted again and after inspecting drawings of the TNT unit, agreed to carry out heat treatment of the area requiring repair.

2. Procedure

a. Preliminary Preparations

All steam pipes, delivery pipes, handrails, a stirrer and coil and the drowning flap mechanism were removed from the area, which was then thoroughly cleaned by a combination of steaming, hot water washing and scrubbing until free of TNT as detected by test solution.

Other areas in the region of the TNT unit were cleared free of visible explosive and all vessels including the other compartments of the unit were filled with water.

b. Description of Heat Treatment System Used

A vertical bulkhead consisting of a wire grid covered with mineral wool insulation material ('Rock Wool') was installed in the unit to isolate the main section of the vessel from the area to be treated.

6 electric heaters were positioned as shown in Figure 1 and spaced from the unit by firebricks. The heaters were secured in position by steel wire or, in the case of the 2 heaters under the floor of the unit, supported by scaffolding poles. The heaters were rated for a maximum of 13.2 Kva each (55 amps at 240 volts) and were wired in a 'star' configuration, 2 heaters being connected in series to each phase of the 3 phase supply.

5 thermocouples were positioned on the basis of their proximity to the areas which were to be repaired. Another thermocouple was placed to measure the temperature of the area which, if any, would be the coolest of the region under treatment, achievement of the specified temperature at this position being an assurance that all areas had attained or exceeded this temperature.

The thermocouples were spot welded to steel plates which were then placed in contact with the unit itself. (For maximum accuracy, the preferred technique is to weld the thermocouples direct to the unit but this was considered to be too hazardous).

As a further check on the whole region, surfaces and welds were spotted with a temperature sensitive paint which changes from green to pink after 10 minutes heating at 410°C and tablets having a melting point of 399°C were phased randomly in the area.

When all the heaters, thermocouples and associated wires and cables were positioned, the sides, top and bottom of the unit were covered with 'Rock Wool'. In addition 2 heavy insulation mats were placed on top of the unit.

c. Heat Treatment

The required programme was to allow the temperature to rise to 300°C uncontrolled and then to increase the temperature at a rate of 150°C per hour to the range 425°C to 450°C. The temperature was maintained in this range for 2 hours after which the heaters were switched off and the unit allowed to cool in still air.

All heating controls and temperature recording equipment were positioned outside the mound of the building and nobody was permitted within the building whilst the work was in progress.

4. Assessment

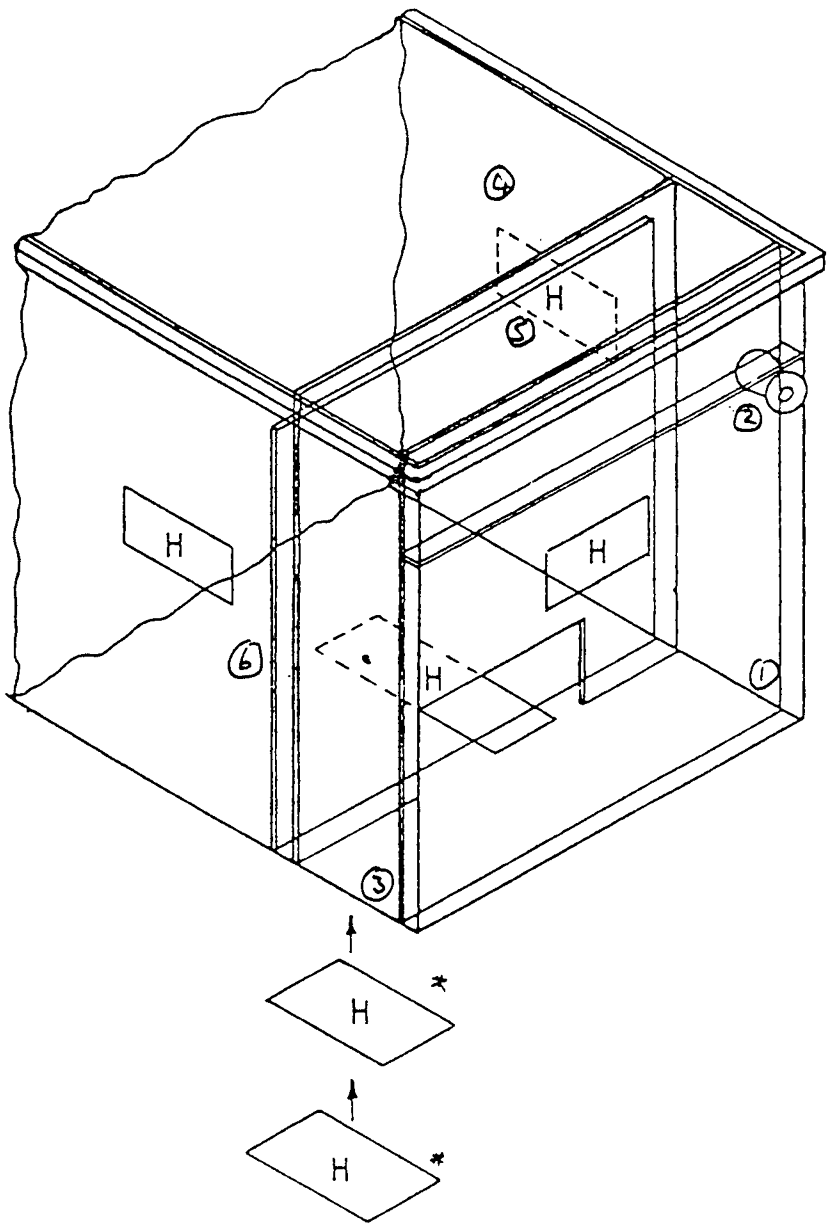
The recording chart showed that the required temperature programme had been met. Inspection of the unit revealed the spots of temperature sensitive paint had all changed colour. All tablets placed in the treated region had fused.

Apart from the inevitable heat staining there was no damage to the unit as a result of this heat treatment.

Repairs were carried out successfully.

ARRANGEMENT OF ELECTRIC HEATERS.

(H = ELECTRIC HEATER)



* THESE TWO HEATERS PLACED UNDERNEATH FLOOR OF N8/T9

O THERMOCOUPLE POSITIONS

ANNEX B FIGURE 1

ANNEX 'C'

DEMOLITION OF BUILDING 3/48A ON THE RDX SECTION

1. Introduction

Building 3/48A had previously been used for 2 major activities; shell breakdown in the immediate post war years and RDX/TNT cracking and packing for the past 30 years. The refurbished building is required for an RDX/TNT mixing and pelleting plant.

2. Preliminary Techniques

2.1 Test Solution

A test solution of sodium hydroxide in methanol and acetone was used to determine the extent of contamination. The test solution develops a red colour in contact with TNT. Contamination was found in the paint layers and at many points where dust had settled.

The whole building was thoroughly hosed by the Fire Brigade to remove dust.

2.2 Paint Remover

Pipework on the drench system, ducting on the air removal system and nuts and bolts were contaminated. These areas were treated with an approved paint remover before dismantling with non-ferrous tools.

2.3 Dust Under the Asphalt Floor

There was evidence to suggest that explosive dust had penetrated between the asphalt floor and the concrete base. The floor area was segregated, sand-bagged and flooded with water. The asphalt was lifted with a non-ferrous pick before being removed to the burning ground for disposal.

3. Major Demolition

3.1 Clerestory Concreted Roof Beam

Breaking out the concrete from the RSJ was commenced using non-ferrour tools under running water. This proved expensive in terms of both tooling and time. Repeated tests did not indicate the presence of explosive contamination so the tooling was changed to steel although retaining the running water. No problems were encountered thereafter and this part of the demolition was completed on time.

3.2 Girders

When the concrete cladding had been removed from the girders they were cut up using an oxy-acetylene torch. The following precautions were taken:

a. The girders were thoroughly hosed down and cleaned.

b. The area on the beams where cutting was to occur was test solution checked.

c. The floor was sand-bagged and flooded to quench the sparks from cutting.

The cutting was completed without problems.

3.3 Floor Over the Underground Ducts

Underground ducts had been fitted to supply ventilation air to the building. The relatively thin duct covering was broken out using steel tooling on hand-held compressed air jack hammers with running water applied to the tool tip and with the duct flooded.

3.4 Main Floor

The technique here was to use a remotely controlled large hydraulic hammer with steel tooling and copious running water.

The operator sits in a protected cab some 3 to 5 metres remote from the hammer point, a safer option than the traditional hand-held jack hammer. The procedure dealt with 0.38 metres thickness of concrete and an area of 40 square metres was cleared in 6 hours.

3.5 Walls

It had been intended to retain most of the walls and re-use them in the new building. However, it was eventually established that the building had no piled foundations and the decision was taken to demolish and rebuild. The walls were pulled inwards by the back actor shovel, drenched with water and broken up before removal.

EFFECTS
OF
CARBON MONOXIDE
ON
PERSONNEL

Presented

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by

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EFFECTS OF CARBON MONOXIDE ON PERSONNEL

New weapons and the vehicles on which they mount have and will continue to become increasingly complex. These weapons are potentially more demanding, and challenges need to be addressed. One important challenge is the need to accurately monitor and control the amount of toxic substances, generated by weapon systems, that may endanger the soldiers who will operate the systems.

Toxic fumes generated from various sources can have debilitating effects on the efficiency of occupants and operators of vehicles and ground equipment. The insidious nature of these effects underscores the necessity for detecting, measuring, and eliminating these hazards to the extent possible. The overall problem that must be addressed is the potential exposure of soldiers to carbon monoxide (CO), ammonia (NH_3), oxides of sulfur (SO_2), oxides of nitrogen (NO_2), lead fumes (Pb), and other harmful substances. The exposures are likely to be relatively intense (above present Federal standards for occupational exposure), brief (1 hour or less), and rapidly repeated (as often as six times daily for periods as long as 14 days). Such exposures may occur when soldiers are trained to use various weapon systems or while in combat (ref 16).

While exposures to emissions from ammunition propellants may be encountered by soldiers in a variety of operational settings, the US Army's concern about the potentially harmful effects of various air pollutants has focused on exposures in various armored vehicles. Armored crewmen are vulnerable to the adverse effects of exposure to the toxicants mentioned because of the closely confined and sometimes poorly ventilated space inside the vehicles, and because of the proximity of personnel to the emission sources (ref 16).

Carbon monoxide (CO) is an invisible, odorless gas which gives no warning to its victims, although it is sometimes mixed with other more obvious gases. CO is one of the most dangerous industrial hazards and one of the most wide-spread. Approximately 2,000 persons die each year as a result of exposure to CO. At least 10,000 workers suffer from exposure to harmful levels of CO and those who experience milder effects number in the millions (ref 3). There is also good reason to believe that many cases, both fatal and nonfatal, go unreported or are incorrectly diagnosed each year. Motor vehicles account for 60 percent of all CO emissions annually. A lethal concentration of CO can be reached in a closed garage within 10 minutes. Concentrations of 25 parts per million (ppm) are commonly encountered on expressways in major metropolitan areas. During weather inversions, concentration could reach as high as 100 ppm (ref 23).The nonindustrial segment of the population most exposed to CO are tobacco smokers.

In 1973, the National Institute for Occupational Safety and Health (NIOSH) recommended a standard for CO exposure specifying an 8-hour time-weighted average (TWA) of 35 ppm with a ceiling value of 200 ppm. The recommended standard was designed for the safety and health of workers performing a normal 8-hour day, 40-hour week assignment; it was not designed for the population at large. The recommended TWA standard of 35 ppm CO is based on a carboxyhemoglobin (COHb) level of 5 percent, the amount of COHb that a person engaged in sedentary activity would be expected to inhale in 8 hours during continuous exposure. The ceiling concentration of 200 ppm is based upon the restriction of employees to noncontinuous exposures to CO above 35 ppm which would not be expected to significantly alter their level of COHb. The recommended standard does not take into consideration the smoking habits of workers since the level of COHb in chronic cigarette smokers has generally been found to be

in the 4 to 5 percent range before CO exposure.

As of this date, the NIOSH standard has not been adopted by the Occupational Safety and Health Administration (OSHA). The OSHA standard (29CFR1910.1000(a)), based on a COHb level of about 6 percent, specifies a 50 ppm TWA for an 8-hour period (ref 6). No ceiling level is specified in this standard.

MIL-STD-1472C (ref 15) states "...that carbon monoxide in personnel areas shall be reduced to the lowest level feasible. Personnel shall not be exposed to concentrations of carbon monoxide (CO) in excess of values which shall result in carboxyhemoglobin (COHb) levels in their blood greater than the following percentages: 5 percent COHb (all system design objectives and aviation system performance limits); 10 percent COHb (all other system performance limits) ..."

While it is recognized that toxic gases, such as nitrogendioxide (NO_2), sulphur dioxide (SO_2), and other dangerous substances, can affect the health of personnel, this investigation was confined to the study of carbon monoxide.

The information contained in this report was developed through a search of existing available literature on the subject of CO and from data collected during toxic gas testing conducted at APG (ref 27). The APG instrumentation used to collect toxic gas data, discussed in this report, is housed in a mobile van and consists of four MSA LIRA 202 carbon monoxide analyzers, four HNU 200 ammonia analyzers, one TECO Model 14 nitrogen dioxide analyzer, and one TECO Model 40 sulfur dioxide analyzer. The electrical output from each analyzer is amplified and recorded on a paper chart by means of two SOLTEX Model KA-62, 6-pen recorders. The average CO concentration is monitored by the instruments and the COHb level is then calculated by an in-line

updated so that it will have the capability to monitor vehicles on the move. An in-line computer will calculate and record TWA and COHb levels instantly.

The collected information from this investigation was combined and analyzed to determine the problems confronting personnel who would be exposed to the measured concentrations of CO. Analytical models obtained from the investigation were used to develop hypothetical situations that would represent real-world conditions. The information was also used by APG to determine requirements and specifications to update monitoring equipment used to measure CO during tests of weapons systems.

The first subjective sign of CO intoxication in a healthy subject can be in the form of a headache when the COHb level in the subject's blood reaches 10 to 20 percent. If exposure continues, symptoms may progress to dizziness, nausea, a feeling of weakness, mental confusion, impaired vision, and an awareness of palpitations and breathing difficulties before collapsing. The major effect of CO is due to its ability to impair oxygen transport by the blood, thus resulting in hypoxia (ref 1). Normally, oxygen from the lungs is carried through the body by the blood's hemoglobin. But when CO is inhaled, the hemoglobin (Hb) grabs the poison first, ignoring the available oxygen. Without oxygen passing through the bloodstream, the victim suffocates. At lower levels, the CO still takes over part of the oxygen-carrying capability of the blood. CO is a safety hazard as well as a health hazard. A person suffering from CO intoxication is likely to cause accidents, possibly injuring himself and others, while performing military functions such as operating vehicles, mechanical/electrical equipment, or weapon systems.

The affinity of Hb for CO is about 200 to 300 times as great as oxygen. The affinity constant (M) can be expressed as the number of moles of oxygen which must be

present with each mole of CO in order to maintain an equilibrium saturation of Hb. The combination of Hb with CO forms a compound known as COHb. A normal male has about 15 grams of Hb per 100 ml of blood and each gram of Hb is capable of carrying 1.34 ml of oxygen. This results in the transport of 20 ml of oxygen per 100 ml of blood which represents a maximum oxyhemoglobin $(HbO_2)_{max}$ of 0.2 ml per ml of blood (ref 16). Because the Hb binding sites have a preference for CO, the HbO concentration is always less than $(HbO_2)_{max}$ by a value of (COHb) (ref 16). The relationship between the partial pressures of oxygen and CO in the lungs and their combinations with Hb can be expressed by the equation:

$$P_{co} \text{ X } M/P_{02} = COHb/O_2Hb$$

where

P_{co} and P_{02} = Partial pressures of CO and O_2, respectively

M = Affinity constant of CO for Hb

As with many other gases, the degree of harm from CO is a product of concentration (ppm) multiplied by the length of exposure (time). For a healthy nonsmoking male doing a sedentary type of activity (work effort = 1), the relationships in Table 1 have been proposed as a rough guide in estimating effects of exposure to CO (ref 12). However, if the work effort was to be increased to a moderate work level (work effort = 4) the level of COHb would increase to dangerous levels (see column 1) in Table 1.

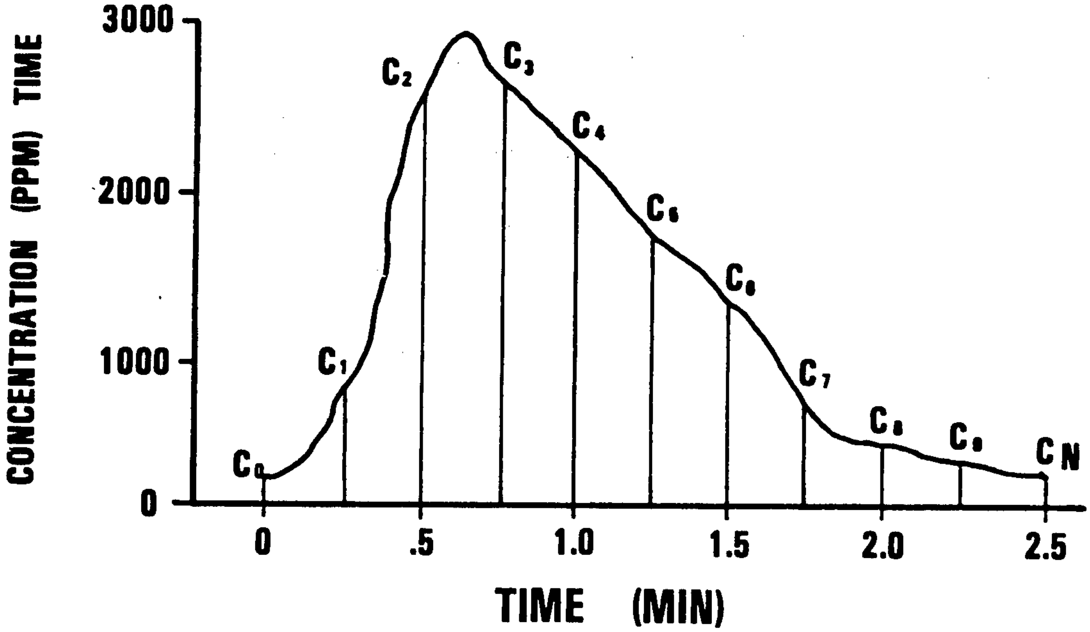
The exposure of 600 ppm-hour would cause the COHb level to rise dangerously to approximately 40 percent. In fact, the safe exposure would have to be less than 150 ppm-hour. It is obvious then that the OHSA standard of 50 ppm, TWA for 8 hours would not be valid when a 400 ppm-hour exposure is permitted for personnel who are working at moderate levels.

In the real world of toxic gas exposures, the amount of CO contaminating the atmosphere will not necessarily be constant. It is unlikely that a given concentration, say 50 ppm, can be measured steadily for a period of 8 hours. Measurements of CO and other toxic gases during testing at APG vary from a point near zero and rise steadily until a maximum peak is reached and then fall steadily when the source of CO has been removed. The scenario can be described by the typical exposure concentration curve in Figure 1 (ref 9).

PROBABLE EFFECTS OF EXPOSURE TO CO

CONCENTRATION (ppm) X TIME (HR)	COHb (%) WE = 1	PROBABLE EFFECT	COHb (%) WE = 4	PROBABLE EFFECT
300 ppm · hour	8.0	NO PERCEPTIBLE EFFECT	20.0	HEADACHE
400 ppm · hour	10.0	OSHA TWA	27.0	HEADACHE AND NAUSEA
600 ppm · hour	16.0	JUST PERCEPTIBLE EFFECT	40.0	DANGEROUS TO LIFE
900 ppm · hour	24.0	HEADACHE AND NAUSEA	60.0	FATAL
1,500 ppm · hour	39.0	DANGEROUS TO LIFE	> 60.0	FATAL

TABLE 1



TYPICAL EXPOSURE CONCENTRATION CURVE

$$A = \int_{t=o}^{tn} f(t)dt$$

$$A = h/3\left[(C_o+C_n) + 4\,(C_1+C_3+\ldots+C_{n-1})+2(C_2+C_4+\ldots+C_{n-2})\right]$$

A = AREA UNDER THE CURVE (AVE. CONCENTRATION)

h = TIME INTERVAL BETWEEN POINTS

N+1 = No. OF POINTS

C = CONCENTRATION AT TIME t_n

FIGURE 1

The area under the curve represents the average concentration of CO over a period of time. The greater the number of points used, the greater the degree of accuracy in calculating the area. The area is calculated as follows:

$$h = 0.25 \text{ minute}$$

$$A = 0.25/3 \left(\left(100 + 260\right) + 4\left(900 + 2{,}600 + 1{,}600 + 600 + 300\right) + 2\left(2{,}600 + 2{,}100 + 1{,}200 + 400\right)\right) = 3{,}080\text{ppm}$$

The COHb level for a person, exposed to this concentration for a period of 2.5 minutes and doing level 4 type of activity, would be approximately 11.58%. This person would be considered over-exposed, and some action to prevent or reduce this exposure would need to be taken. It has also been recognized that when a person performs exercise or work during CO inhalation, the maximum work time before exhaustion will be reduced, depending both on COHb and exercise levels. Two important parameters to be considered are the diffusion rate (D_L) of CO through the lungs (ml/min) and the ventilation rate (V_a) (ml/min). The following assumptions listed in Table 2 have been made for various levels of activity (ref 15).

ASSUMPTIONS FOR VARIOUS LEVELS OF ACTIVITY

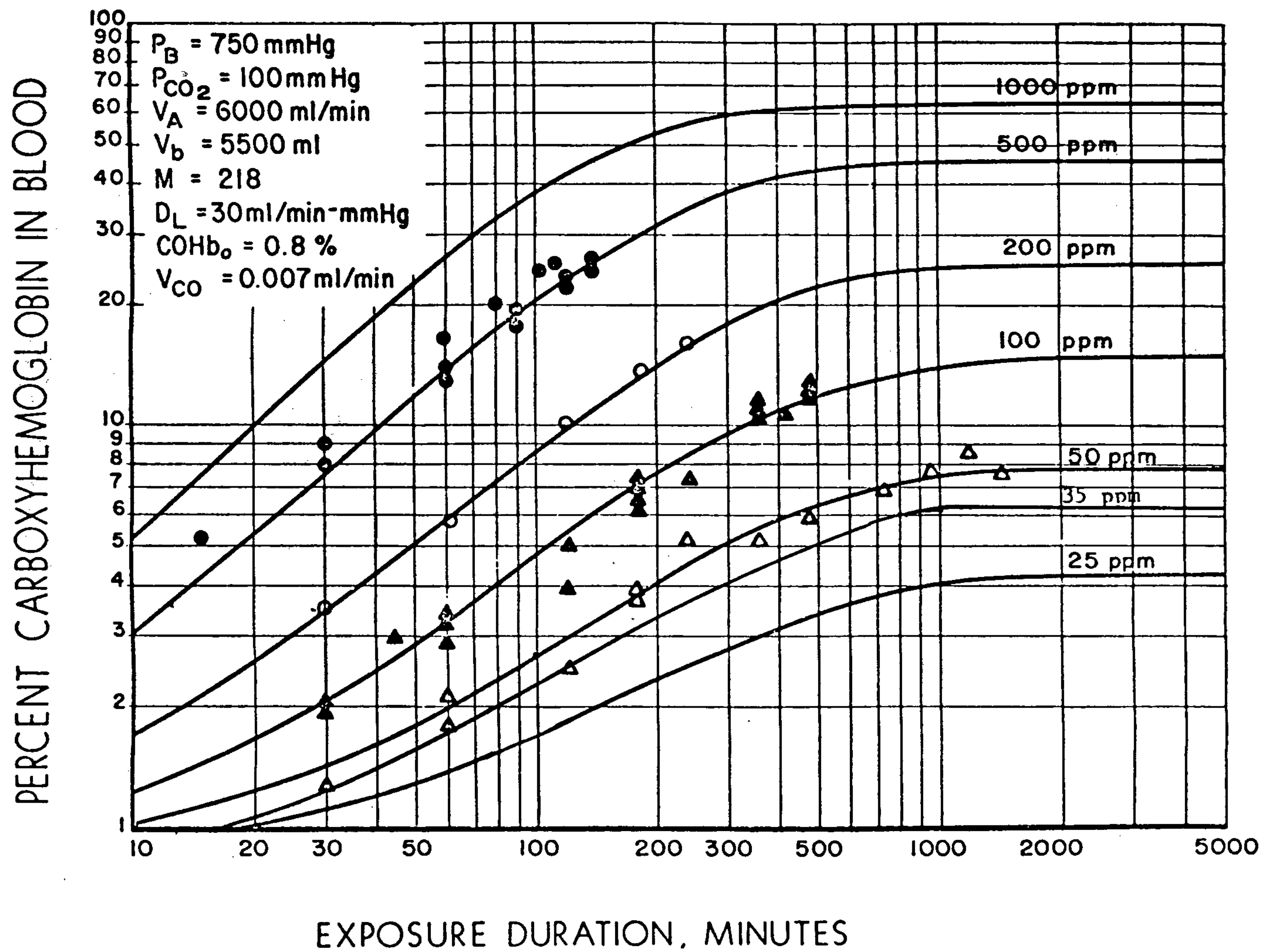
WORK EFFORT	TYPE OF ACTIVITY	DIFFUSION RATE (D_L)	VENTILATION RATE (V_a)
1.	SEDENTARY	30 ml/min	6,000 ml/min
2.		35 ml/min	12,000 ml/min
3.	LIGHT WORK	40 ml/min	18,000 ml/min
4.	MODERATE WORK	50 ml/min	24,000 ml/min
5.	HEAVY WORK	60 ml/min	30,000 ml/min

TABLE 2

The rate at which the blood becomes saturated with CO is therefore directly proportional to cardiac output. Consequently, a person working vigorously will note the onset of symptoms and signs much more quickly than one who is sedentary or at rest (i.e., a person running around in a building seeking an escape route from a fire will be overcome more quickly than will someone sleeping (ref 15).

In 1965, Coburn et al (CFK) (ref 1) published a definitive study on the role of endogenous CO production rate, pulmonary CO diffusing capacity, and other recognized variables. The CFK equation was later tested by Stewart et al (ref 1) and Peterson and Stewart (ref 1) in experiments with human volunteers. It was concluded that the ability of the CFK equation to predict the effects of CO exposure on blood COHb levels was astonishingly good in normal young adult males (ref 1). This equation was later used in a number of studies, one of which was published by NIOSH in 1972, recommending a standard for occupational exposure to CO. The standard has not yet been adopted by OSHA; however, the CFK equation as published by NIOSH has been used extensively in various Government standards to predict levels of COHb resulting from CO exposure. COHb saturations obtained during experimental human exposure to CO by Stewart et al (ref 19) are imposed on the theoretical absorption curves (fig. 2). The results of the comparisons showed that the experimental data fit the CFK (ref 5) model very well.

ABSORPTION OF CARBON MONOXIDE



Stewart, R. D., et al: Experimental Human Exposure to Carbon Monoxide. _Arch. Environ. Health._ 21:154-164, 1970.

FIGURE 2

CFK equation. The CFK equation (ref 18) has become a model for estimating changes in COHb concentration in the blood. The equation once integrated takes the following form:

$$\frac{\dfrac{[COHb]P_{CO_2}}{[O_2Hb]M} - V_{CO}\left[\dfrac{1}{D_L} + \dfrac{P_B - P_{H_2O}}{V_A}\right] - P_{I_{CO}}}{\dfrac{[COHb]_0 P_{CO_2}}{[O_2Hb]M} - V_{CO}\left[\dfrac{1}{D_L} + \dfrac{P_B - P_{H_2O}}{V_A}\right] - P_{I_{CO}}} = e^{-\dfrac{P_{CO_2}t}{MV_b[O_2Hb]\ \dfrac{1}{D_L} + \dfrac{713}{V_A}}}$$

has been rearranged for programming as follows:

$$\text{CO in air (ppm)} = \frac{1316\ [(AC - V_{CO}B + a\ (V_{CO}B - AD)]}{1 - a}$$

where

$$A = \frac{P_{C - O_2}}{M[O_2H_b]}$$

$$B = \frac{1}{D_L} + \frac{P_L}{V_A}$$

$C = [COHb]_t$ = COHb concentration (ml CO/ml blood) at time t.

$D = [COHb]_0$ = "background" COHb (ml CO/ml blood) at time = 0.

V_{CO} = Rate of endogenous CO production (ml/min)

$$a = e^{-\frac{tA}{VbB}}$$

V_b = blood volume

$P_{C - O_2}$ = PO_2 in capillaries (mm Hg)

$[O_2Hb]$ = oxyhemoglobin conc. (ml/ml blood)

M = CO/O_2 affinity for Hb

CFK Equation Continued

V_a = ventilation rate (ml/min)

D_L = 30 ml/min-mmHg

V_{CO} = 0.007 ml/min

V_b = 5,500 ml

$P_c - O_2$ = 100 mm Hg

(O_2Hb) = 0.2 ml/ml blood

M = 218

P_b - 760 mm of mercury

The empirical equation in MIL-STD-759A (ref 10) used to predict the rise in COHb in humans was also derived from the CFK equation and was transformed as follows:

$$\% \ COHb_t = \% \ COHb_o \left(e^{-t/2398B}\right) + 218 \left(1 - e^{-t/2398B}\right)\left(.007B + CO_{ppm}/1316\right)$$

where

$\%COHb_t$ = Predicted COHb

$\%COHb_o$ = Initial COHb

t = Exposure in minutes

COppm = CO exposure in parts per million

B = $1/D_L + (Pb - 47)\ V_a$

ABSORPTION OF CARBON MONOXIDE

As levels of COHb increase, the proportion of absorbed CO decreases due to an increase in the average back pressure of CO in the blood of the lung capillaries. Theoretically, the rate of CO uptake would be proportional to the difference between alveolar CO partial pressure (P_{CO}) and the average back pressure of CO in the blood of lung capillaries. Both values rise during the course of exposure. The back pressure rises slowly at first and then rapidly as Hb saturation increases. As the saturation increases, alveolar P_{CO} rises because progressively less CO is extracted by the blood from the inspired air; when equilibrium between P_{CO} in the capillaries and the alveoli is reached, absorption ceases (ref 1). Figure 3 shows the COHb for resting adults exposed to constant concentrations of CO of 10, 50, and 100 ppm for 30 hours

When the CO exposure is terminated, the level of COHb will fall to its pre-exposure level. The rate of excretion is assumed to be equal to approximately 250-minute biological half-life.

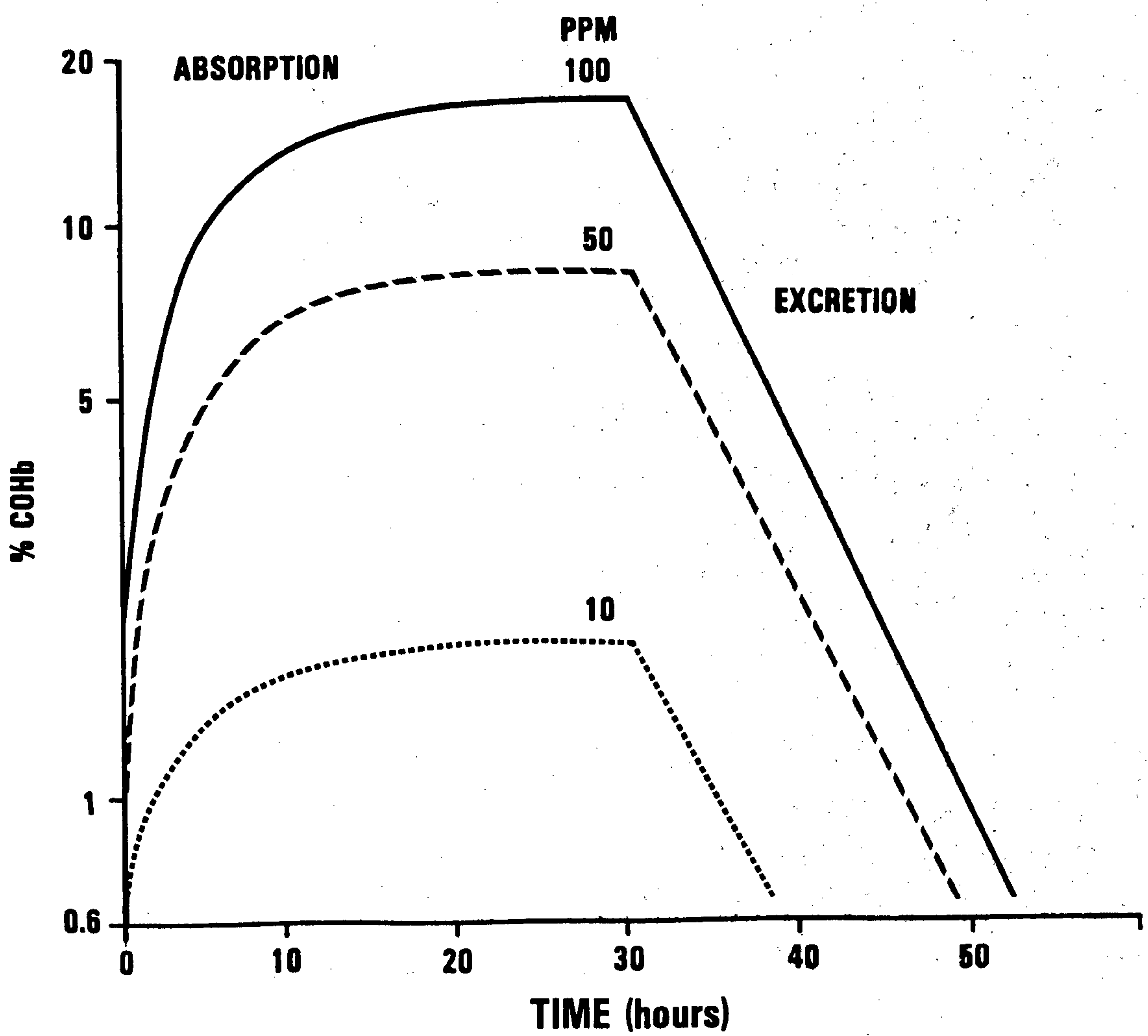


FIGURE 3

It is therefore apparent that unless the partial pressures of CO and O_2 are taken into consideration, the CFK equation would not show that a level of equilibrium has been reached.

While the Stewart tests showed that the experimental data fit the CFK equation very well, those data compared to the modified CFK equation showed that the level of COHb may overpredict (ref 23). Therefore, because of the variables that must be considered when calculating COHb levels with the CFK equation, the results are sometimes questionable. Furthermore, MIL-STD-1472C and MIL-HDBK-759A have recognized the difficulty in obtaining actual blood COHb levels in the operational environment. A method using breath alveolar CO concentrations of test subjects was demonstrated by Stewart, et al (ref 6). The accuracy and simplicity of this techinique has opened a practical field method for the rapid estimation of blood COHb levels in occupational groups (ref 6).

The Stewart methodology does not address CO exposure profiles. It estimates the blood COHb levels resulting from the summation of previous CO exposures (ref 6). Thus, this method is ideally suited to the biological monitoring program in the operational setting.

<u>Elimination of CO</u>. Most of the CO is eliminated unchanged through the lungs and is similiar in many ways to absorption. Elimination is rapid at first, but the last traces are eliminated very slowly. CO is eliminated exponentially; so it is useful to discuss the elimination rate in terms of biological half-life. The normal elimination of CO is quite slow because of its greater affinity for Hb than that of oxygen. The rate of excretion of CO can be calculated with the

CFK equation. The value of $COHb_o$ in equation (7) would be the highest $COHb_t$ level following the exposure, and the COHb would be the level to which it falls following a given time period. The rate of excretion using equation (7) is based on a biological half-life of 250 minutes for a healthly person at rest in an atmosphere of fresh air (free of contaminants). It is interesting to note that the biological half-life can be reduced by administering 100 percent oxygen by a tight fitting mask. The biological half-life is thus reduced to approximately 80 minutes. The biological half-life can be further reduced to about 24 minutes by administering 100 percent oxygen in a hyerbaric setting of 3 atomospheres of pressure (ref 22).

It is also interesting to note that the function $e^{-t/2398B}$ in equation (7) is equal to e^{-ta/V_bB} from equation (6). Both of these terms represent the decay of COHb. Consequently, both the terms are equal to the decay equation used to measure the amount of decay of radioactive material. The following equation (ref 32) can thus be substituted to calculate the elimination of CO from the blood.

$$N_t = N_o e^{-kt}$$

where

N_t = Final COHb level

N_o = Initial COHb level

K = Disintegration factor

= 0.693/Half-Life or 0.693/250 = 0.0028

t = Time (min)

Comparing this with the equation from MIL-HDBK-759A, we find that the function $e^{-t/2398B} = e^{-0.0028t}$ which equals the above equation for the decay of COHb in an atmosphere of fresh air.

To calculate the amount of time needed to purge the COHb level to a normal level of approximately 1 percent or to some other designated level, the decay formula can be transposed as follows:

$$t\ (\mathrm{min}) = \frac{\log_e N_t - \log_e N_o}{-K}$$

The computer program illustrated in this paper is a revision of a program to calculate COHb levels at various crew stations in armored vehicles (ref 26). This program is written in FORTRAN IV language, and a simulated scenario was run to produce the printout. The commander, driver, and loader crew stations were assigned average CO concentrations of 507, 497, and 473, respectively, and COHb level was calculated for each time period listed in the left-hand column. The program was run at work levels equalling one and four for comparison (see printouts). The gunner's position was assigned a concentration of 50 ppm to demonstrate the COHb levels associated with OSHA'S standard. This data is plotted on a graph (Figure 4). A difference of almost 2 percent COHb can be expected in a nonsmoking healthy male person.

LEVEL OF COHb DURING EXPOSURE OF 50 PPM OF CO

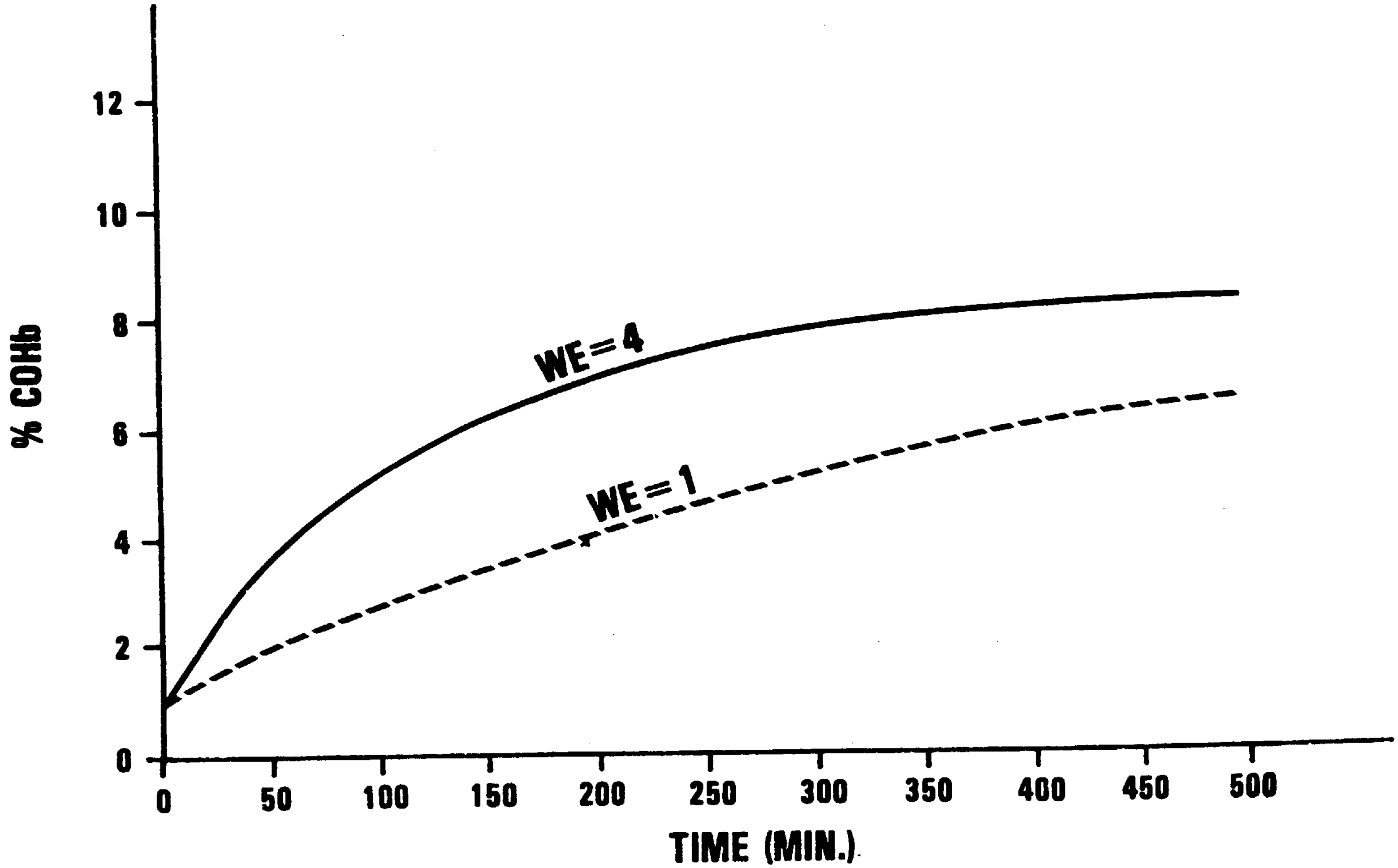


FIGURE 4

```
$CONTROL USLINIT,FILE=1
C  PROGRAM COHB3 REVISED 'FROM TECH NOTE 1-80(S.STEINBERG,AUTHOR)'
       PROGRAM COHB3
       DIMENSION COO(4),COHBT(4),PPM(4),IBWS(4),DL(5),
     +    VA(5),B(5),DCOHB(4)
      CHARACTER*70 HDR
       DATA     DL/30.0,35.0,40.0,50.0,60.0/,
     +      VA/6000.0,12000.0,18000.0,24000.0,30000.0/
      DISPLAY 'SET TOF'
      ACCEPT IDUM
      IN=1
100     READ  (IN,110) HDR,PB,COO
110     FORMAT (A70/F3.0,4(1X,F4.2))
      LINES=0.0
        TIME=0.0
        HTIME=0.0
290     WRITE (6,300) HDR,PB
300     FORMAT (1H1,'SCENERIO:',A70/
     +         20X,'BAROMETRIC PRESSURE=',F6.1,' (MM HG)'/
     +        T4,'CUM TIME',T15,'D-TIME',
     +         T23,'-------- COMMANDER --------',
     +         T51,'--------- DRIVER ----------',
     +         T79,'--------- LOADER ----------',
     +         T107,'-------- GUNNER ----------'/
     +         T17,'MIN',
     +         4('   WE CO-PPM D-COHB T-COHB  ')/)
         WRITE (6,350) HTIME,TIME,COO
350      FORMAT (1X,F5.2,1X,F6.1,7X,4(19X,F8.2,1X))
         DO 400 I=1,5
400      B(I)=1.0/DL(I) + (PB-47.0)/VA(I)
500      READ (IN,510) TI,(IBWS(J),PPM(J),J=1,4)
510      FORMAT (F5.1,4(1X,I1,1X,F5.0))
         IF (TI.LT.0..OR.IBWS(1).EQ.0.) GO TO 715
         IF (TI.EQ.0.0) GO TO 100
         DO 600 K=1,4
         TERM=EXP(-TI/2398.0/B(IBWS(K)))
         COHBT(K)=COO(K)*TERM + 218.0*(1.0-TERM)*(.007*B(IBWS(K))
     +    +PPM(K)/1316.0)
600      DCOHB(K)=COHBT(K) - COO(K)
         TIME=TIME+TI
         HTIME=TIME/60.0
         LINES=LINES+1
         IF(MOD(LINES,50).EQ.0) WRITE(6,675)HDR
675      FORMAT (1H1,'SCENERIO: ',80A1/
     +          T4,'CUM TIME',T15,'D-TIME',
     +           T23,'--------COMMANDER--------',
     +            T51,'---------DRIVER----------',
     +        T79,'---------LOADER----------',
     +           T107,'--------GUNNER----------'/
     +           T3,'HRS',T10,'MIN',T17,'MIN',
     +           4('   WE CO-PPM D-COHB T-COHB  ')/)
          WRITE (6,700) TI,
     +    (IBWS(M),PPM(M),DCOHB(M),COHBT(M),M=1,4)
700       FORMAT (12X,F7.1,4(I4,F8.0,F7.2,F8.2,1X))
710      GO TO 500
715      STOP
720      END
```

SCENERIO:TEST COMPUTER PROGRAM COHB3

BAROMETRIC PRESSURE= 760.0 (MM HG)

D-TIME	COMMANDER				DRIVER				LOADER				GUNNER			
MIN	WE	CO-PPM	D-COHB	T-COHB	WE	CO-PPM	D-COHB	T-COHB	WE	CO-PPM	D-COHB	T-COHB	WE	CO-PPM	D-COHB	T-COHB
				1.00				1.00				1.00				1.00
15.0	4	507.	9.82	10.82	4	497.	9.63	10.63	4	473.	9.16	10.16	4	50.	.87	1.87
30.0	4	507.	18.48	19.48	4	497.	18.11	19.11	4	473.	17.23	18.23	4	50.	1.64	2.64
60.0	4	507.	32.85	33.85	4	497.	32.20	33.20	4	473.	30.62	31.62	4	50.	2.91	3.91
90.0	4	507.	44.02	45.02	4	487.	42.27	43.27	4	473.	41.04	42.04	4	50.	3.90	4.90
114.0	4	507.	51.14	52.14	4	487.	49.10	50.10	4	473.	47.67	48.67	4	50.	4.53	5.53
120.0	4	507.	52.71	53.71	4	487.	50.61	51.61	4	473.	49.14	50.14	4	50.	4.67	5.67
135.0	4	507.	56.30	57.30	4	487.	54.05	55.05	4	473.	52.48	53.48	4	50.	4.99	5.99
150.0	4	507.	59.46	60.46	4	487.	57.09	58.09	4	473.	55.43	56.43	4	50.	5.27	6.27
180.0	4	507.	64.71	65.71	4	487.	62.13	63.13	4	473.	60.33	61.33	4	50.	5.73	6.73
240.0	4	507.	71.97	72.97	4	487.	69.10	70.10	4	473.	67.09	68.09	4	50.	6.38	7.38
300.0	4	507.	76.36	77.36	4	487.	73.31	74.31	4	473.	71.18	72.18	4	50.	6.76	7.76
330.0	4	507.	77.85	78.85	4	487.	74.74	75.74	4	473.	72.57	73.57	4	50.	6.90	7.90
360.0	4	507.	79.01	80.01	4	487.	75.86	76.86	4	473.	73.65	74.65	4	50.	7.00	8.00
390.0	4	507.	79.91	80.91	4	487.	76.72	77.72	4	473.	74.49	75.49	4	50.	7.08	8.08
420.0	4	507.	80.61	81.61	4	487.	77.40	78.40	4	473.	75.15	76.15	4	50.	7.14	8.14
480.0	4	507.	81.58	82.58	4	487.	78.33	79.33	4	473.	76.05	77.05	4	50.	7.23	8.23
420.0	4	507.	80.61	81.61	4	487.	77.40	78.40	4	473.	75.15	76.15	4	50.	7.14	8.14
450.0	4	507.	81.16	82.16	4	487.	77.92	78.92	4	473.	75.65	76.65	4	50.	7.19	8.19

SCENERIO: TEST COMPUTER PROGRAM COHB,
BAROMETRIC PRESSURE= 760.0 (MM HG)

D-TIME MIN	COMMANDER WE	CO-PPM	D-COHB	T-COHB	DRIVER WE	CO-PPM	D-COHB	T-COHB	LOADER WE	CO-PPM	D-COHB	T-COHB	GUNNER WE	CO-PPM	D-COHB	T-COHB
				1.00				1.00				1.00				1.00
15.0	1	507.	3.35	4.35	1	497.	3.28	4.28	1	473.	3.12	4.12	1	50.	.30	1.30
30.0	1	507.	6.57	7.57	1	497.	6.44	7.44	1	473.	6.12	7.12	1	50.	.59	1.59
60.0	1	507.	12.62	13.62	1	497.	12.37	13.37	1	473.	11.76	12.76	1	50.	1.14	2.14
90.0	1	507.	18.19	19.19	1	487.	17.47	18.47	1	473.	16.96	17.96	1	50.	1.64	2.64
114.0	1	507.	22.33	23.33	1	487.	21.44	22.44	1	473.	20.82	21.82	1	50.	2.02	3.02
120.0	1	507.	23.32	24.32	1	487.	22.39	23.39	1	473.	21.74	22.74	1	50.	2.11	3.11
135.0	1	507.	25.73	26.73	1	487.	24.71	25.71	1	473.	23.99	24.99	1	50.	2.32	3.32
150.0	1	507.	28.05	29.05	1	487.	26.93	27.93	1	473.	26.15	27.15	1	50.	2.53	3.53
180.0	1	507.	32.40	33.40	1	487.	31.11	32.11	1	473.	30.21	31.21	1	50.	2.93	3.93
240.0	1	507.	40.11	41.11	1	487.	38.51	39.51	1	473.	37.39	38.39	1	50.	3.62	4.62
300.0	1	507.	46.65	47.65	1	487.	44.79	45.79	1	473.	43.49	44.49	1	50.	4.21	5.21
330.0	1	507.	49.53	50.53	1	487.	47.56	48.56	1	473.	46.18	47.18	1	50.	4.47	5.47
360.0	1	507.	52.19	53.19	1	487.	50.11	51.11	1	473.	48.66	49.66	1	50.	4.71	5.71
390.0	1	507.	54.64	55.64	1	487.	52.46	53.46	1	473.	50.94	51.94	1	50.	4.93	5.93
420.0	1	507.	56.90	57.90	1	487.	54.63	55.63	1	473.	53.04	54.04	1	50.	5.14	6.14
450.0	1	507.	58.97	59.97	1	487.	56.62	57.62	1	473.	54.98	55.98	1	50.	5.33	6.33
480.0	1	507.	60.89	61.89	1	487.	58.46	59.46	1	473.	56.77	57.77	1	50.	5.50	6.50
510.0	1	507.	62.65	63.65	1	487.	60.15	61.15	1	473.	58.41	59.41	1	50.	5.66	6.66
540.0	1	507.	64.27	65.27	1	487.	61.71	62.71	1	473.	59.92	60.92	1	50.	5.80	6.80
600.0	1	507.	67.15	68.15	1	487.	64.47	65.47	1	473.	62.60	63.60	1	50.	6.06	7.06

EXAMPLES

Example 1

Assume that a nonsmoking individual was exposed to 6,000 ppm of CO for a period of 1 minute. This individual was doing sedentary level or work while exposed. His physical characteristics were as follow:

Ventilation rate (V_a) = 6,000 ml/min.
Diffusion rate (D_L) = 30 ml/min.
Blood volume (V_b) = 5,500 ml
Using CFK equation

where

t = 1 min
B = 0.15
$\%COHb_t$ = 0.8% (nonsmoker)
ppmCO = 6,000 ppm

$$\%COHb_t = 0.8\left(e^{-1/(2398)(.15)}\right) + 218\left(1 - e^{-1/(2398)(.15)}\right)\left((.007)(.15) + 6{,}000/1{,}316\right)$$

$$= 0.8\ (0.997) + 218\ (0.0027)(4.56)$$

$$= \underline{3.48\%}$$

Example 2

Assume that the same individual (example 1) was exposed, except that he was a chronic smoker and was doing heavy work at the time of exposure.

then

$$\%COHbt = 5\left(e^{-1/(2398)(.04)}\right) + 218\left(1 - e^{-1/(2398)(.04)}\right)\left((.007)(.04) + 6{,}000/1{,}316\right)$$

$$= 5\ (0.989) + 218\ (0.011)\ (4.56)$$

$$= \underline{15.88\%}$$

The difference in %COHb level following the same exposure level and time due to difference in work activity in addition to being a smoker is significant. The individual in example 2 could possibly be subjected to symptoms of COHb such as headaches, and his ability to perform work safely could be affected.

Example 3

At APG, toxic-fumes investigations are conducted to determine the concentration of toxic gases to which a crew is exposed to when executing sustained rates of weapons fire during various vehicle conditions and defensive or offensive scenarios. The study scenario is usually representative of anticipated operational situations. The ideal scenario encompasses periods when maximum sustained rates of fire are achieved by weapons systems and the crew space environmental control system is maximally stressed to remove firing contaminants. This ensures the crew exposure to maximum design concentrations of toxic gases or fumes at the time of high workload requirements. This ideal scenario represents a "worst-case" operational situation and during stationary fire or fire-and-maneuver exercises.

A toxic fume investigation is also conducted to determine the concentration of toxic gases resulting from the operation of vehicles and other engine-driven equipment.

A typical firing condition test matrix is usually represented in Table 4. (The scenario may vary according to the needs of the system being tested.)

FIRING CONDITION TEST MATRIX

Condition[a] No.	Rounds Fired: 25 mm[b]	Rounds Fired: 7.62 mm	Hatches[c]	Crew Ventilator[d]	Personnel Heater[e]
1	5	—	Closed	On	Off
2	5	—	Closed	Off	Off
3	5	—	Open	On	Off
4	10	—	Open	On	Off
5	10	—	Closed	On	Off
6	5	—	Closed	On	On
7	10	—	Closed	On	On
8	10	—	Closed	On	On
9	1	—	Closed	On	On
10	1	—	Open	On	On
11	—	23	Closed	On	On
12	—	21	Open	On	On
13	—	23	Open	On	Off
14[f]	105	200	Closed	On	On
15[g]	210	300	Closed	On	On

[a] During all firing conditions the engine was operated at 1400 rpm (tactical idle) with the exception of conditions 11, 12 and 13 when it was operated at 700 rpm (normal idle).

[b] The 25 mm was fired at high rate (≈182 rds/min) during all conditions, with the exception of condition 10, when it was fired at low rate (≈92 rds/min).

[c] Driver" hatch and the two rear doors were closed during all conditions; only the two turret hatches were either opened or closed.

[d] The crew ventilator (located on top of hull behind the driver) pulls air out of the vehicle, causing negative pressure within the vehicle.

[e] Heater operated on high setting.

[f] 3-Minute scenario.

30-Minute scenario.

TABLE 4

Based on the data collected during each firing trial, the information is used to calculate the COHb level of each crew member. Each test condition is evaluated to determine whether any of the crew would be exposed to harmful concentrations of CO or other toxic fumes. Figures 5 and 6 represent the results of the test data for conditions 8 and 15 (all hatches closed and heater and vent on). This evaluation is presented for each condition.

Figure 5 shows that the concentration of CO was minimal for positions 2, 3, and 4 and would not raise the COHb of those crew members. Therefore, no firing restrictions are necessary for these positions. However, position 1 was restricted to 140 trials (1400 rounds of 25mm ammo) because the COHb level of COHb was predicted to reach 10 percent at that time. Approximately 6 hours would be needed to fire the 1400 rounds and over 6 hours would be needed to permit the crewmembers' COHb level to reduce to 1 percent. Consequently only two such missions (2,800 rounds) could be permitted during a 24 hour period.

COMPUTED CARBOXYHEMOGLOBIN (COHB) LEVELS

AVERAGE FIRING CONDITION B

BAROMETRIC PRESSURE: 760.0 MM HG

	POSITION 1	POSITION 2	POSITION 3	POSITION 4
AVERAGE CO LEVEL, PPM	63.00	39.00	39.00	49.00
TIME OF FIRE MISSION, MINUTES	2.48	2.30	.93	2.28
COMPUTED COHB LEVEL AFTER FIRST TRIAL, %	1.20	1.00	1.00	1.00
NUMBER OF TRIALS TO REACH 10% COHB	140	****	****	****
COMPUTED COHB LEVEL AFTER N TRIALS, %	10.00	1.00	1.00	1.00
COMPUTED COHB LEVEL AFTER N+1 TRIALS, %	10.01	1.00	1.00	1.00
TIME FOR COHB TO DECAY TO 1%, HRS	6.20	0.00	0.00	0.00
NUMBER OF ALLOWABLE MISSIONS PER 24 HRS	2	****	****	****

CREW POSITIONS:

POSITION 1: DRIVER
POSITION 2: CENTER OF TURRET
POSITION 3: LEFT SIDE CREW
POSITION 4: RIGHT SIDE CREW

**** NOTE: NO FIRING RESTRICTIONS WITH RESPECT TO CO

TABLE 5

Figure 6 represents condition 15 where both the 25mm and 7.62mm weapons were fired simultaneously for 30 minutes (210 rounds of 25mm and 300 rounds of 7.62mm). It was predicted that the COHb level would have reached approximately 6 percent for each crew member. Two trials would have raised the COHb level to slightly under 10 percent. Consequently, a total of about 7.5 hours would include the firing and decay times, permitting three such missions within 24 hours.

COMPUTED CARBOXYHEMOGLOBIN (COHB) LEVELS

AVERAGE FIRING CONDITION 15

BAROMETRIC PRESSURE: 750.0 MM HG

	POSITION 1	POSITION 2	POSITION 3	POSITION 4
AVERAGE CO LEVEL, PPM	107.00	106.00	100.00	109.00
TIME OF FIRE MISSION, MINUTES	42.48	42.21	41.29	43.18
COMPUTED COHB LEVEL AFTER FIRST TRIAL, %	6.04	5.96	5.58	6.21
NUMBER OF TRIALS TO REACH 10% COHB	2	2	2	2
COMPUTED COHB LEVEL AFTER N TRIALS, %	9.56	9.44	8.82	9.83
COMPUTED COHB LEVEL AFTER N +1 TRIALS, %	12.03	11.89	11.11	12.35
TIME FOR COHB TO DECAY TO 1%, HRS	6.08	6.05	5.87	6.15
NUMBER OF ALLOWABLE MISSIONS PER 24 HRS	3	3	3	3

CREW POSITIONS:

POSITION 1: DRIVER
POSITION 2: CENTER OF TURRET
POSITION 3: LEFT SIDE CREW
POSITION 4: RIGHT SIDE CREW

TABLE 6

In conclusion, then, it is apparent that the Army as well as industrial workers need to be concerned with the effects of CO on personnel. The nature of the build-up of some of the effects underscores the necessity for detecting, measuring, and as much as possible, eliminating this hazard. The military is at the forefront of technology and procedures for controlling CO, and recognizes that more needs to be done. Non-military agencies such as OSHA need to update standards and serve as a conduit to advise industry and government agencies about the hazard of CO and the latest means of protection.

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An Examination of Injury Criteria for Potential Application to Explosive Safety Studies

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ABSTRACT

A state-of-the-art assessment of research into and the modeling of wounding mechanisms and phenomena is described. The results of an extensive survey of the literature are presented along with recommendations for replacement of the presently used "58 ft-lb rule". The data and models located have been evaluated with respect to applicability to explosive safety studies which typically require quantification of the fragment impact hazards to personnel. Major topics for discussion include penetrating and non-penetrating injury mechanisms and models, wounding thresholds, military incapacitation criteria, and existing safety criteria, as well as recommendations for formulation of new criteria.

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1. Preface

The work described in this paper was sponsored and funded by the Department of Defense Explosive Safety Board (DDESB) in March 1983 under Project 4A665805M857.

2. Introduction

Present Department of Defense Explosive Safety Board (DDESB) doctrine establishes the acceptable fragmentation hazards to personnel exposed to accidental explosions. Presently, the acceptable limit is exposure to not more than 1/600 square feet of hazardous fragments. Current DDESB policy is to define a "hazardous fragment" as one which has at least 58 foot-pounds of kinetic energy. Clearly, the use of this, or any other injury criterion will effect the calculated distances required to limit personnel to the acceptable exposure limit.

Use of the 58 ft-lb criterion to define fragmentation hazards has been criticized in recent years because, 1) it is not based on any well defined injury classification scheme, 2) it is overly simplistic in nature, and 3) a general feeling that there must be something better available in light of all the research into wounding phenomena and effects that has taken place over the last several decades.

The objectives of this investigation were to review the literature on kinetic energy wounding, assess the state-of-the-art, determine the applicability of existing data and models to explosive safety studies, and if appropriate, recommend new criteria. In addition, since the far-field hazards relate mainly to large (ranging from a few grams to several kilograms), relatively slow moving fragments with speeds approaching their free-fall velocity, the range of variables over which the various criteria are valid was to be determined and methods for extrapolating to the mass range of interest considered. The discussion

presented here will focus on the major findings of the investigation with respect to the availability of a suitable 58 ft-lb law replacement candidate. Additional details concerning other important research not covered in this paper, along with the bibliography which resulted from the current study, can be found in a soon to be published BRL report.

3. Literature Search

The survey of the literature was conducted by a contractor, Ketron, Inc. Several hundred technical reports and journal articles were compiled, reviewed, and analyzed with the above mentioned objectives in mind. A majority of the documentation was located by querying the DTIC (Defense Technical Information Center), NTIS (National Technical Information Service), TRIS (Transportation Research Information Service), BIOSIS (Biological Research Abstracts), and MEDLINE (Medical Literature Analysis and Retrieval Systems) automated data bases. In addition, a significant amount of relevant information was obtained through numerous informal discussions with various researchers in ballistics and related fields. A comprehensive bibliography containing 304 citations was compiled from the reviewed literature.

4. Penetrating Trauma

In the search for relevant literature, a natural division seemed to occur between penetrating injury and non-penetrating injury data. Accordingly, the documents reviewed were categorized as relating to either one or the other. The overwhelming majority of data and models located pertain to research into penetrating injury phenomena. The following discussion will focus on only a few of the criteria which were established as a result of this research.

4.1. 58 Ft-Lb Criterion

The literature abounds with references to the 58 ft-lb energy criterion. Rohne is usually given credit for establishing this criterion which was probably intended as nothing more than a rough rule of thumb. The date usually attributed to its origin is 1906. The actual quote, translated from the 1906 article[1] by Rohne is "To remove a human from the battlefield, a kinetic energy of 8 mkg is sufficient according to the prevailing view in the German artillery community;....". Actually, an earlier article by Rohne, written in 1896 under the same title, contains the same statement; in neither case does he cite any data, experimental or otherwise, to substantiate this view. Interestingly, in a subsequent paragraph, he states that "Horses require a larger impetus to incapacitate them. Colonel Langlois set forth a kinetic energy of 19 mkg in his report "L'artillerie de campagne en liason avec les autres armes",... Again, it is unfortunate that the basis for these statements is not explained. Rohne, while not discussing the validity of the 58 ft-lb criterion, used it to determine ranges at which various military rifles ceased to be effective.

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[1] Rohne, H.; Schiesslehre fur Infanterie, 1906.

While the exact origin and basis for the 58 ft-lb figure remains obscured, other researchers have considered its validity as a criterion with varying results. Sterne[2], for example, in 1955, suggested that Rohne's criterion applied to lethality rather than to a sublethal effect. Indeed, penetrating injury research shows that lethal injuries can occur at impact kinetic energy levels significantly less than 58 ft-lbs. Without giving additional consideration to other parameters such as missile shape, size, mass, and possibly impact location, energy based hazard assessments can be misleading.

4.2. Incapacitation Criteria

In the years since Rohne, numerous researchers have investigated projectile induced kinetic energy wounding usually in hopes of relating, in some fashion, some form of ballistic dose to the projectile's casualty producing potential. The U.S. Army's incapacitation criteria, which resulted from extensive research conducted over the last three decades, were established to predict the incapacitating effects of wounding by fragmenting munitions, bullets, and flechettes. Certain of these criteria have, on occasion, been applied to hazard type analyses, but in general they are used as effectiveness criteria in the context of weapon system analyses. Briefly, the approach taken to establish these criteria was as follows.

An initial set of four steel fragment simulators was chosen to represent the class of munition fragments of interest. The projectile masses and the velocities at which they were assessed are shown in the following table.

Table 4-1. Incapacitation Projectile Data Base

Projectile	Mass	Experimental Striking Velocities
0.85 gr, steel sphere	0.055 gram	305, 914, 1524 meters/second
2.1 gr, steel cube	0.136 gram	305, 914, 1524 meters/second
16.0 gr, steel cube	1.04 gram	305, 914, 1524 meters/second
225 gr, steel cube	14.58 gram	152, 305, 762 meters/second

Basically, for each of these mass-velocity combinations, firings were conducted against biological targets to generate actual wound data. The nature of the observed wounds was delineated by assigning to it a

[2] Sterne, T. E., and A. J. Dziemian; "Provisional Probabilities of Incapacitation by a Caliber 0.30 Rifle-Bullet, Ball M-2," BRLM 949, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, Dec 1955.

wound class which related incapacitation to loss of arm and leg function.

The most widely applied criteria of this type are the curves published by Kokinakis and Sperrazza in 1965[3]. The correlation relates striking mass and velocity of an impacting steel fragment to the conditional expected level of incapacitation given a single random hit. The functional form of the relationship is:

$$P(I/H) = 1 - e^{-a(mv^{A}-b)}$$

where
e = base of natural logarithm
m = fragment mass (grains)
v = fragment striking velocity (ft/sec)
A,a,b,n = fitted constants which depend on tactical role, time after wounding, and body part hit.

Since these criteria are based upon the physical requirements and tactical functions related to infantry soldiers in the assault, defense, reserve, and supply roles, it would be inappropriate to apply them to situations involving threshold injury levels to non-military personnel.

4.3. Other Penetrating Trauma Models

In 1967, Kokinakis and Sperrazza[4] published data on the ballistic limits of skin and clothing, based on experimental firings of steel projectiles. Until recently, this skin penetration criterion was used by the U.S. Army as the "official" safety criterion for assessing threshold fragmentation hazards. However, in 1978 Lewis[5], et al developed an empirical formula for estimating the probability of skin penetration by various projectiles, including low density fragments. Of interest to

[3] Kokinakis, W. and Sperrazza; " Criteria for Incapacitating Soldiers with Fragments and Flechettes," BRL Report 1269, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1965, (CONFIDENTIAL).

[4] Sperrazza, J. and W. Kokinakis, "Ballistic Limits of Tissue and Clothing," BRL TN 1645, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1967.

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them was the environmental debris such as rocket motor fragments and other secondary projectiles that pose a hazard to personnel. Backblast debris from small rocket-motor launched weapons could include wood fragments from vegetation and structures, metal fragments from the weapon, rocklike fragments from stone or concrete structures and stones from the ground. Accordingly, they included in their investigation three sizes of wood cylinders having diameters and lengths equal to 0.5 inch (1.27 cm), 1.0 inch (2.54 cm), and 1.5 inch (3.81 cm) and irregular gravel weighing approximately 2 grams. Other missiles were 4 grain (0.259 gram), 16 grain (1.035 gram), and 64 grain (4.14 gram) steel cubes, a 0.85 grain (0.055 gram) steel sphere and a 16 grain (1.035 gram) tungsten cube. These projectiles were fired at sections of goat skin backed with 20 percent gelatin at 10 degrees C. Striking velocity was treated as a test variable.

One objective of the study was to determine the probability of complete skin perforation (full-thickness skin laceration) since the authors had equated this occurrence to a hazardous condition- the assumption being that given a complete penetration of the skin layer, the potential for deeper penetration into various parts of the body also exists. Since a fragment perforates or fails to perforate the skin, the Walker - Duncan Method[6] could be used to estimate the probability in terms of a single variable X defined by some function of the test variables. In this instance, the authors selected for their model

$$X = \ln [(MV^2)/A]$$

where m = mass of the projectile (grams)
v = velocity of the projectile (meters/sec)
A = presented area of the projectile (sq cm).

The Walker-Duncan estimation is then given by

$$P = \frac{1}{1 + \exp[-(a + bx)]}$$

where: a and b are curve fitting constants
and x is as defined above.

Employing curve fitting techniques, the authors determined a and b values for the targets shown in Table 4-2.

[6] Walker, S. H. and D. B. Duncan; "Estimation of the Probability of an Event as a Function of Several Independent Variables", Biometrika 54:167-179, (1967).

Table 4-2 Logistic Function Coefficients

Target	a	b
Bare Skin	-28.42	2.94
Two-Layer Uniform	-48.47	4.62
Six-Layer Uniform	-50.63	4.51

Probability curves for skin penetration as a function of $\ln[(MV^2)/A]$ are shown in Figure 4.1.

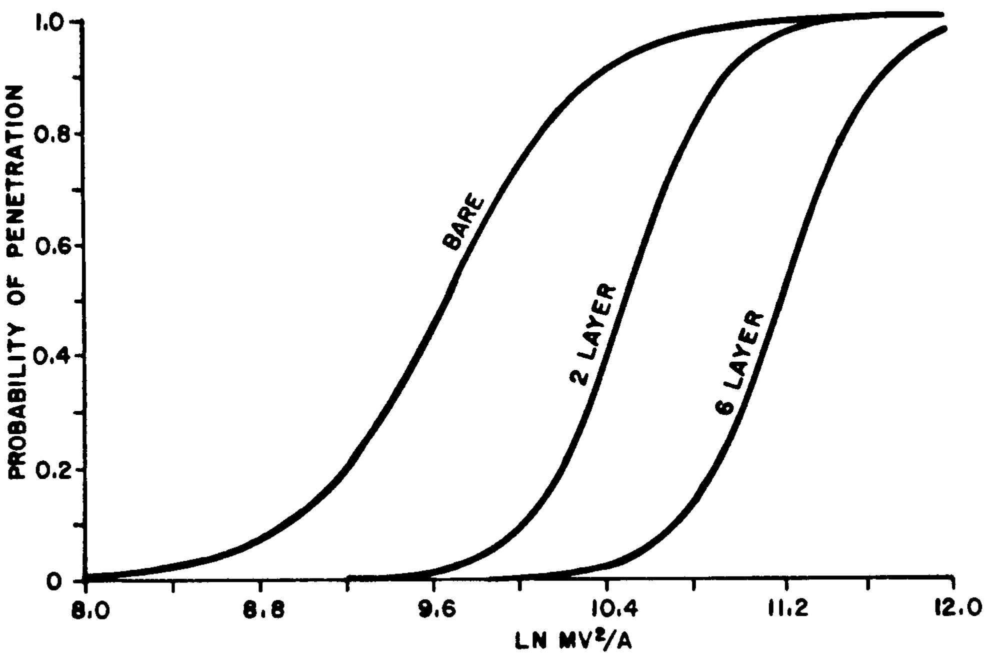

Figure 4.1 Walker-Duncan Curves Estimating the Probability of Skin Penetration as a Function of Projectile Parameters. (Reproduced from Reference 5).

5. Non-Penetrating Trauma

Although penetration is the primary damage mechanism of interest here, it was felt that the potential for injury from non-penetrating missiles exists as well. Non-penetrating injury, or blunt trauma, generally refers to any injury caused by a victim either striking or being struck by a non-piercing object. Objects causing projectile induced blunt trauma are characterized by their low velocity, lack of cutting and piercing features and size.

Most of the research pertaining to projectile-induced blunt trauma has occurred since the passage of The Omnibus Crime Control and Safe

Streets Act of 1968. Much of the research was sponsored by The National Institute of Law Enforcement and Criminal Justice and performed by multi-disciplined teams of researchers from the U.S. Army's Biophysics Laboratory located at Edgewood Arsenal (EA), Maryland and Land Warfare Laboratory (LWL) at Aberdeen Proving Ground Maryland, and various contractors.

The LWL team of Shank, Thein, Campbell and Wargovich conducted valuable research into the physiological response to the effects of non-lethal weapons[7]. An interesting part of their work involved the classification system they established for measuring these responses.

With regards to the availability of injury criteria for non-penetrating missiles the four-parameter model of Clare, et al[8], apparently represents the "state of the art" in blunt trauma modeling. Given knowledge of the input parameters, (projectile mass, velocity and diameter and target (body) mass) the model predicts the probability of lethality as a result of impact to the thorax. Their model is of the form:

$$P(r) = f(mv^2)/wD)$$

where

- $P(r)$ = probability of response (death, serious injury, etc)
- m = mass of projectile in grams.
- v = impact velocity of the projectile in meters/second.
- w = body mass of the animal in kilograms.
- D = diameter of the projectile in centimeters.

The same model, with appropriate adjustment of the discriminant line intercept, was extended by the authors to fracture/no-fracture data for the liver.

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[7] Shank, E. B., B. K. Thein, D. Campbell and M. J. Wargovich; "A Comparison of Various Less Lethal Weapons," LWL TR-74-79, U.S. Army Land Warfare Laboratory, Aberdeen Proving Ground, MD, June 1974.

[8] Clare, V. R., J. H. Lewis, A. P. Michiewicz and L. M. Sturdivan; "Handbook of Human Vulnerability Criteria Chapter 9. Projectile-Induced Blunt Trauma," EB-SP-76011-9, Department of the Army, Headquarters, Edgewood Arsenal, Aberdeen Proving Ground, MD, May 1976.

As shown in Figures 5.1 and 5.2, the model discriminates between low, medium, and high regions of response/no response. The authors emphasize that they consider the model to be provisional, pending availability of additional data for further validation.

6. Applicability to Explosive Safety

The relevancy of models described in the previous sections can be summarized from an examination of Figure 6.1. To facilitate comparisons of the various relationships, the masses and velocities corresponding to each model's predicted measure were determined. For example, for line B, the masses and velocities are those which correspond to a 50% probability of skin penetration (for steel cubes) according to the model of Lewis.

The presently employed 58 ft-lb law (line A) is shown in comparison with two pairs of penetrating injury relationships. The upper pair, represented by lines B and C, are based on the skin penetration model of Lewis et al. The test mass upper bound was 4.08 grams. Line B is for steel cubes; line C was derived assuming a spherical shape factor. The second pair of lines, represented by lines D and E describe the penetration law of Sperrazza and Kokinakis. The test mass upper bound was 15 grams. Line D is based on steel cubes; line E was derived assuming a spherical shape factor. In addition, the calculated DDESB mass interval of interest[+] is shown in the shaded area.

The two lines labeled "G" represent the relationship of Clare, et al for threshold liver fracture. The bottom solid G-line most directly reflects the test data for which the average animal weight, w, was about, 11.3 kg. The upper dashed G-line is an extrapolation to a man's body weight of 70 kg. Both lines are for low density (average 1.31 g/cm^3) projectiles and the mass test data interval was from 3 grams to 381 grams. Also shown is the LWL blunt trauma relationship for the first damage level (line F).[++] The LWL relationship was not discussed here since it is not directly applicable to humans. It is included because it corresponds to a low level of injury (LWL damage level 1) and is therefore of interest from an injury threshold perspective. Unfortunately, the model is not appropriate for human body weights. With the EA model, weight of the target is an input parameter.

[+] The interval depicted represents a crude estimate of the relevant mass range based on 155 mm projectile data published by Feinstein, D. I., in "Fragmentation Hazards to Unprotected Personnel," IITRI J6176, Engineering Mechanics Division, ITT Research Institute, Chicago, IL for the Department of Defense Explosive Safety Board (DDESB), Washington, DC, January 1972.

[++] The LWL team of Shank et al used a six valued damage level grading system to describe the effects of blunt trauma wounds. Damage level 1, corresponds in general to superficial or slight damage. See reference 7 bottom of page 7.

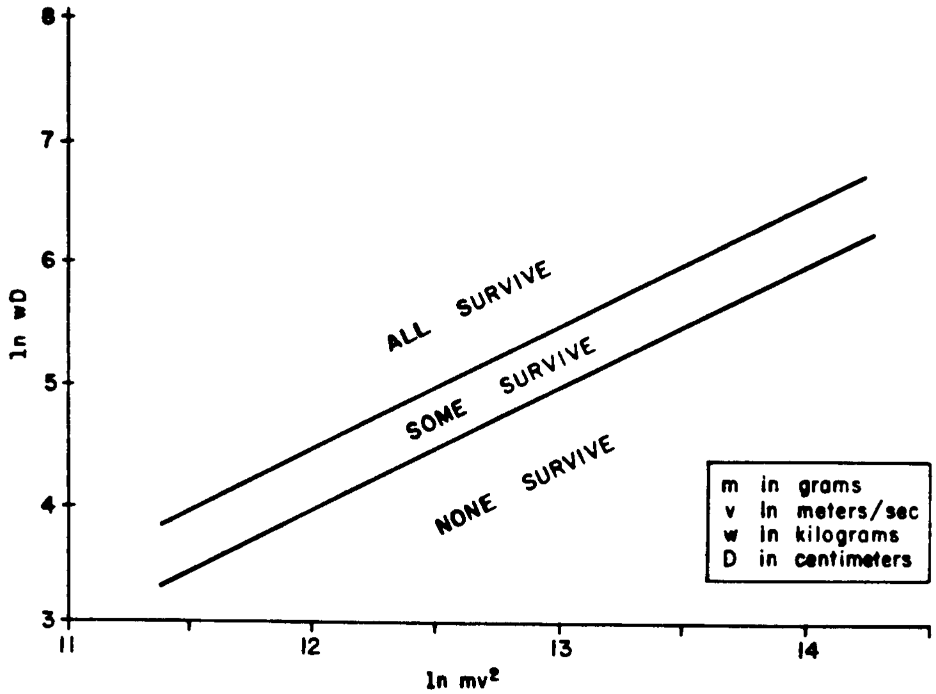

Figure 5.1 Lethal/Non-Lethal Discriminant Lines, Based on EA Four-Parameter Model Applied to Animal Blunt Trauma Data.

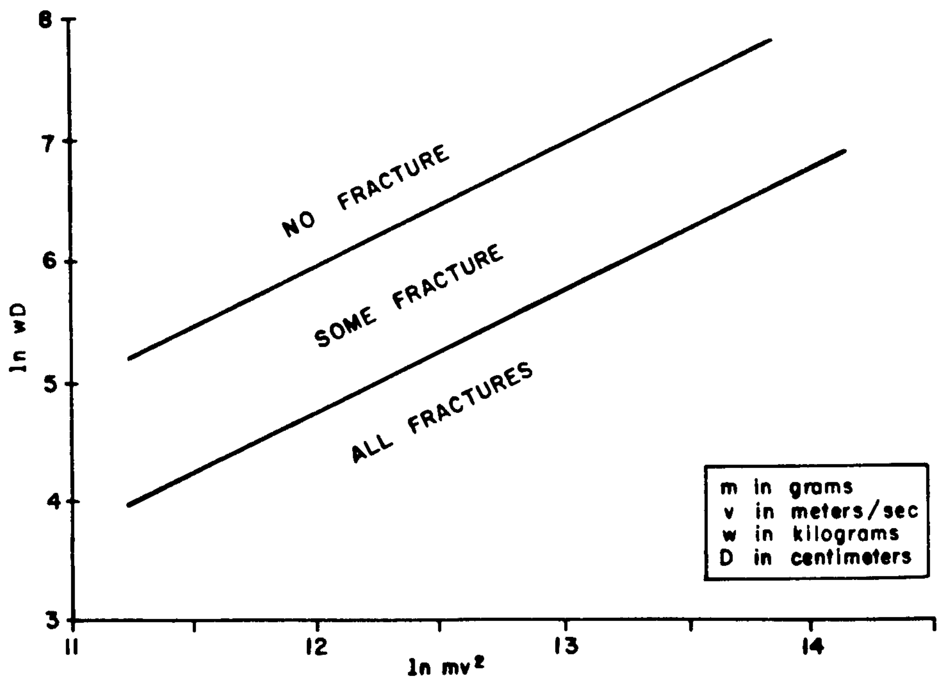

Figure 5.2 Liver Fracture/No Fracture Discriminant Lines, Based on EA Four-Parameter Model Applied to Blunt Trauma Data.

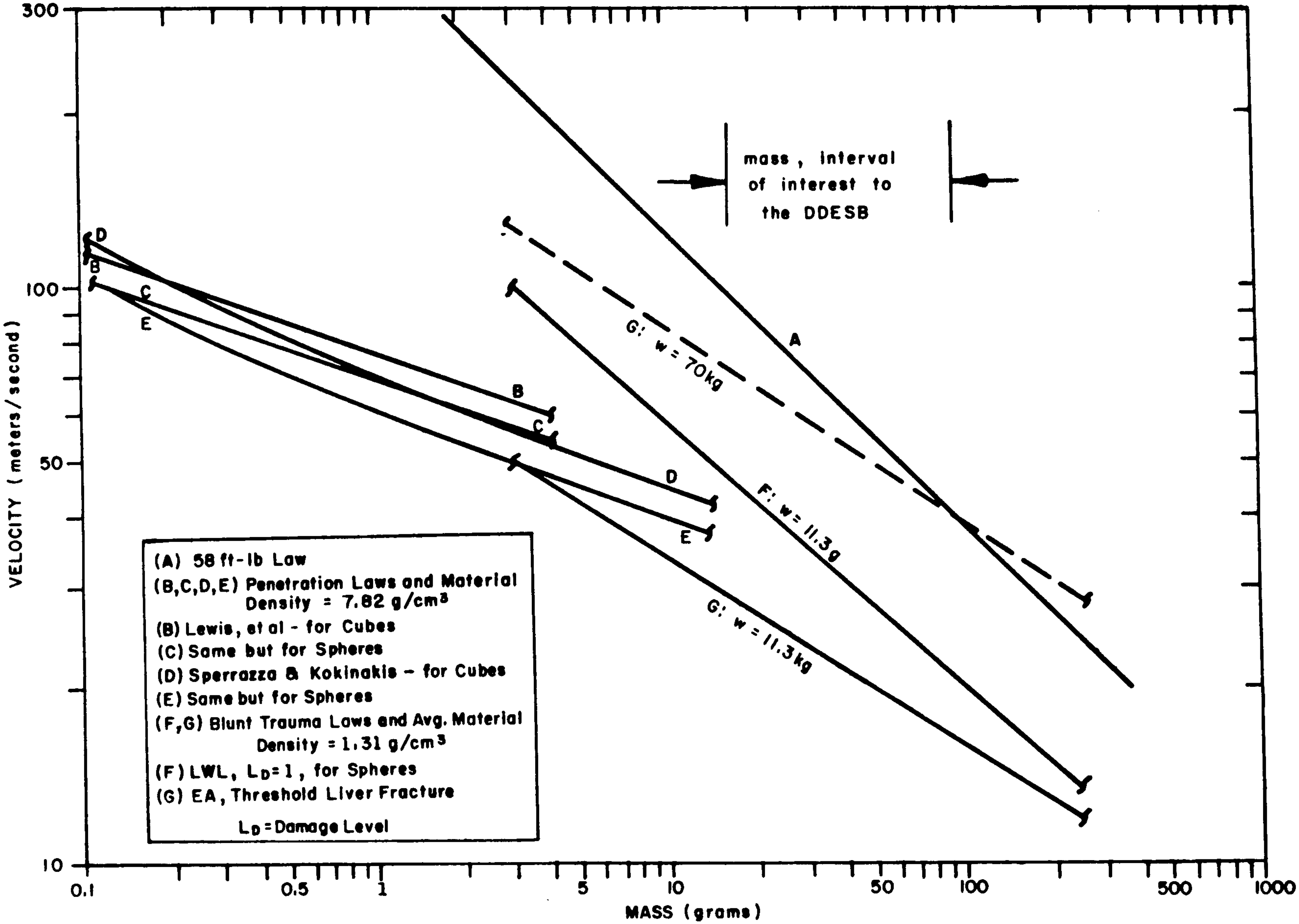

Figure 6.1 Laws, Mass Bounds on Data and DDESB Mass Interval of Interest.

7. Summary and Conclusions

In the attempt to locate criteria which represent an improvement over the currently used 58 ft-lb law, it became obvious that an accurate assessment of the hazards for typical far-field fragments by application of the various criteria located was not possible due to two noted shortcomings, namely:

1.) the lack of non-penetrating injury data for projectiles with densities greater than about 1.31 gm/cm^3,

2.) the lack of penetrating injury data for projectiles with mass greater than about 15 grams.

The above deficiencies are a result of wounding/injury research being concentrated on the effects of small, high velocity, steel projectiles. Where investigations were conducted into non-penetrating trauma, the projectiles of interest were, by design, of low density materials. The assessments and comparisons made in the analysis then are, in some cases, based on severe extrapolations of the existing data bases. For example, in comparing Lewis's skin penetration model with the 58 ft-lb rule, it was necessary to assume the model was valid for fragment masses an order of magnitude larger than those upon which the model is based. Accordingly, there is a critical need to verify the skin penetration curves in the mass ranges of interest, and the blunt trauma relationship for high density materials. Given these model validations/modifications, it is felt that a viable solution to the problem of determining far-field fragment hazards to personnel could involve simultaneous application of the two models mentioned above to quantify the potential for both penetrating and non-penetrating injury. A hazardous condition would be indicated if either criterion was met.

A methodological change of this nature would of course require a concomitant change in philosophy as to just what constitutes an unacceptable hazard to personnel. The economic, social, and political implications of adopting the skin penetration model as a replacement for the 58 ft-lb rule have not been considered in this investigation. In conclusion, we find numerous arguments against the continued use of the 58 ft-lb criterion, the strongest of which concerns its inability to predict a well defined injury level on the basis of mass and velocity alone, and suggest that after further investigation, more meaningful criteria can be formulated by validating other scientifically based models by extending and/or modifying those models through additional experimentation and analysis.

SYMPATHETIC DETONATION OF 16"/50 HC PROJECTILES

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ABSTRACT

As part of the Naval Explosives Safety Improvement Program (NESIP), a series of tests have been conducted to verify predictions concerning the sympathetic detonability of 16"/50 HC projectiles. Analytical studies could not rule out the possibility of sympathetic detonation. Based on the test results, a reaction probability of eleven percent can be estimated. With this estimate of the reaction probability, it is assessed that the 16"/50 HC projectile (loaded with Explosive D) will not mass detonate.

INTRODUCTION

With the reintroduction of the battleship into the active fleet, questions have been raised about some aspects of the ammunition associated with its 16-inch guns. One specific question which was raised is, "Will 16"/50 HC projectiles mass detonate?"

The 16"/50 round is shown schematically in Figure 1. The projectile empty case weight (including base plug and gas check gasket) is 1720 pounds. The projectile is filled with 154 pounds of Explosive D (Ammonium Picrate). The average wall thickness is 3 to 3 1/2 inches.

Previous NESIP (Naval Explosives Safety Improvement Program) work has investigated the sympathetic characteristics of 5"/54 projectiles loaded with both Composition A-3 and Explosive D.[1] Those loaded with Explosive D failed to detonate even when in contact with a donor projectile; those loaded with Composition A-3 sympathetically detonated, even out to significant separations between donor and acceptor. The same held true for pallets of the ammunition-those loaded with Explosive D do not detonate, those loaded with Composition A-3 do.

The 5"/54, 8"/55, and 16"/50 are a family of HC (High Capacity) shells, which have been loaded with Explosive D. The similarities between these three shells should afford a reliable way to estimate the 16"/50 behavior, based on the 5"/54 and 8"/55 data. A comparison of all three projectiles is presented in Table 1.

[1]Porzel, F. B., "A Model and Methods for Control of Sympathetic Detonation," Minutes of the Eighteenth Explosive Safety Seminar, Volume II, San Antonio, Texas, 12-14 Sep 1978.

TABLE 1 HC FAMILY OF PROJECTILES

	5"/54	8"/55	16"/50	16" Scaled*	16" Scaled**
Explosive Weight (lb)	7.8	21.3	154	256	171
Total Weight (lb)	78	258	1874	2556	2064
Explosive/Total Mass	0.10	0.083	0.082	0.10	0.083
Case Thickness (in)	0.7	1.6	3.2-3.5	2.3	3.2

*Scaled up from 5" data

**Scaled up from 8" data

According to the NESIP "Action Criterion",[1] explosive sensitivity is yield dependent, via duration and size. Even though a 5"/54 projectile (loaded with Explosive D) was shown to be safe, i.e., would not sympathetically detonate, it cannot be assumed, a priori, that a 16"/50 projectile is also safe. Since a 16" projectile is over three times the width of a 5" projectile, the loading duration increases and the impact pressure required for sympathetic reaction can decrease by a factor of $(5/16)^{1/3}$ for a 16" projectile relative to a 5" projectile. There is also undocumented evidence that an 8" projectile loaded with Explosive D did mass detonate.[2]

Analyses conducted for this study indicated the following:

1. The 16"/50 HC round (loaded with Explosive D) will possibly mass detonate on contact, from either blast or fragments.

2. The 8" round (loaded with Explosive D) is, at best, marginal.

3. The 5"/54 round (loaded with Explosive D) should not detonate.

Because of the prediction that sympathetic detonation was possible, a limited test program was organized and conducted to verify it. The remainder of this report documents the results of that effort.

EXPERIMENTAL PROGRAM

Since the number of assets available was limited, a simple six-shot experimental program was proposed and fielded. Five shots were conducted with one donor and two acceptor warheads on each shot. This experimental arrangement is shown in Figure 2. The spacing between the donor and acceptor

[2]Daugherty, E., (NAVSEA-06H), private communication.

rounds was varied on each shot to cover the range of 0 to 1 charge diameters. Table 2 presents the spacings used on each shot. The sixth shot consisted of a stack of nine rounds in an hexagonal close-pack arrangement. The center round of this stack was detonated. This arrangement is shown in Figure 3. This close-pack arrangement simulates the actual stacking scheme aboard ship.

All 24 projectiles utilized on this program were from existing Navy stock. They had been inspected by the Naval Weapons Support Center (NWSC), Crane, Indiana, and were rejected for fleet use. The rejections were for a variety of reasons--none of which affected the test program. Some were rejected for stuck fuzes, some for damaged rotating bands, and some for stuck base plug.

Each donor projectile was initiated with approximately 1-pound of Composition C-4 placed in the nose fuze well.

The stated purpose of the tests was to determine if 16"/50 HC projectiles can be made to sympathetically detonate. To address that question, several techniques were used:

1. Witness plates beneath each round.

2. Flash panels to measure the fragment velocity from the acceptor rounds.

3. High speed photography.

4. Airblast.

RESULTS

Table 2 summarizes the results of all the shots. On the first five shots, none of the acceptor projectiles reacted. Figure 4 shows a before and an after of one of the witness plates. Where the donor was located, there is a hole in the plate. Where the acceptors were located, there are no marks or indentations on the plate.

All of the acceptor rounds were thrown considerable distances--up to 431 feet in one case. The location of the acceptor projectiles for all the shots were surveyed. These are shown in Table 3. In addition, they are indicated in a projectile map--Figure 5. (It should be noted here that all measurements are with respect to ground zero).

Each acceptor round was damaged--though there were no case failures or penetrations. In each case, the rotating bands were stripped off. There was evidence of fragment impacts, case flattening, and case deformation, but no case penetrations.

The last shot studied two effects--the effect of confinement and the effect of interaction between rounds. On this shot, six rounds were recovered intact, one appeared to detonate or violently react and one appeared to break apart or deflagrate.

TABLE 2

16"/50 HC SYMPATHETIC DETONATION TEST PROGRAM AND RESULTS

Shot Number	Spacing (inches/diameters+)	Results
2097	0	0/2 reacted
2098	0	0/2 reacted
2099	4,8 (.25, .50)	0/2 reacted
2100	1,2 (.06, .12)	0/2 reacted
2101	12, 15 1/4 (.75, .95)	0/2 reacted
2102		1/8 detonated* 1/8 deflagrated** 6/8 no reaction

*Or violent reaction

**Low order reaction

+Indicated by numbers in parenthesis

At the location of the donor, a hole was punched through the witness plate. At the location of Acceptor I, there was a deformation and tearing of the plate--indicating some type of reaction (Projectile I was never located). The case of Acceptor G was recovered in two pieces. Explosive D remained in the lower portion of the case. Post shot investigation showed evidence of Explosive D on the ground below the trajectory of Acceptor G. (This evidence indicated that G reacted in some manner--but with much less violence than did Acceptor I).

Before detonation, there was a 4' x 4' x 4" steel plate, weighing approximately 2 tons lying on the ground adjacent to ground zero. This plate was thrown approximately 150 feet by the detonation. Two of the acceptor projectiles were thrown over 1000 feet, with one thrown over 1600 feet. The pre- and post-shot locations of each of these projectiles are indicated in Figure 6 and Table 3.

DISCUSSION

The original question which prompted this work was "Will the 16"/50 HC projectiles mass detonate?" The apparent answer is NO, they will not. If you consider that there were a total of 18 possible acceptor projectiles on all six shots, and that only two reacted in any way, an estimate of the probability of reaction is 2/18 or 11%. (NOTE: Because of the limited number of shots, this is, at best, a crude estimate).

In order for a reaction to be self-sustaining, i.e., propagate, the reaction probability must be at least 25% (P_D[3] greater than 1/N, where N is the number of nearest neighbors). Since our estimate (11%) is less than this, the reaction chain is not self-sustaining--i.e., the reaction would die out.

The only reactions observed were those on the nine-projectile stack. This may be due to several reasons: (1) The effects of the confinement produced by the adjacent projectiles leading to some type of focusing or jetting along specific directions or (2) probability--the limitations produced by the small sample size.

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[3] Porzel, F. B., "Technology Base of the Navy Explosives Safety Improvement Program," Minutes of the Nineteenth Explosive Safety Seminar, Los Angeles, CA, 9-11 Sep 1980.

TABLE 3 FINAL POSITIONS OF ACCEPTOR PROJECTILES

SHOT NUMBER	PROJECTILE DESIGNATION*	RANGE (ft)	EVELATION (ft)	BEARING (0)
2097	L	202	18	110
	R	170	39	273
2098	L	184	15	104
	R	251	51	288
2099	L	431	19	114
	R	213	45	283
2100	L	145	17	93
	R	277	29	305
2101	L	105	7	94
	R	122	21	274
2102	A	1609	-49	39
	B	1286	-79	336
	C	530	46	314
	E	151	23	81
	F	405	68	300
	G (upper)	515	-33	132
	G (lower)	872	-50	119
	H	1015	-52	126
	PLATE	160	38	269

*L is the projectile on the left, looking toward ground zero
R is the projectile on the right, looking toward ground zero.

FIGURE 1. 16"/50 HC PROJECTILE

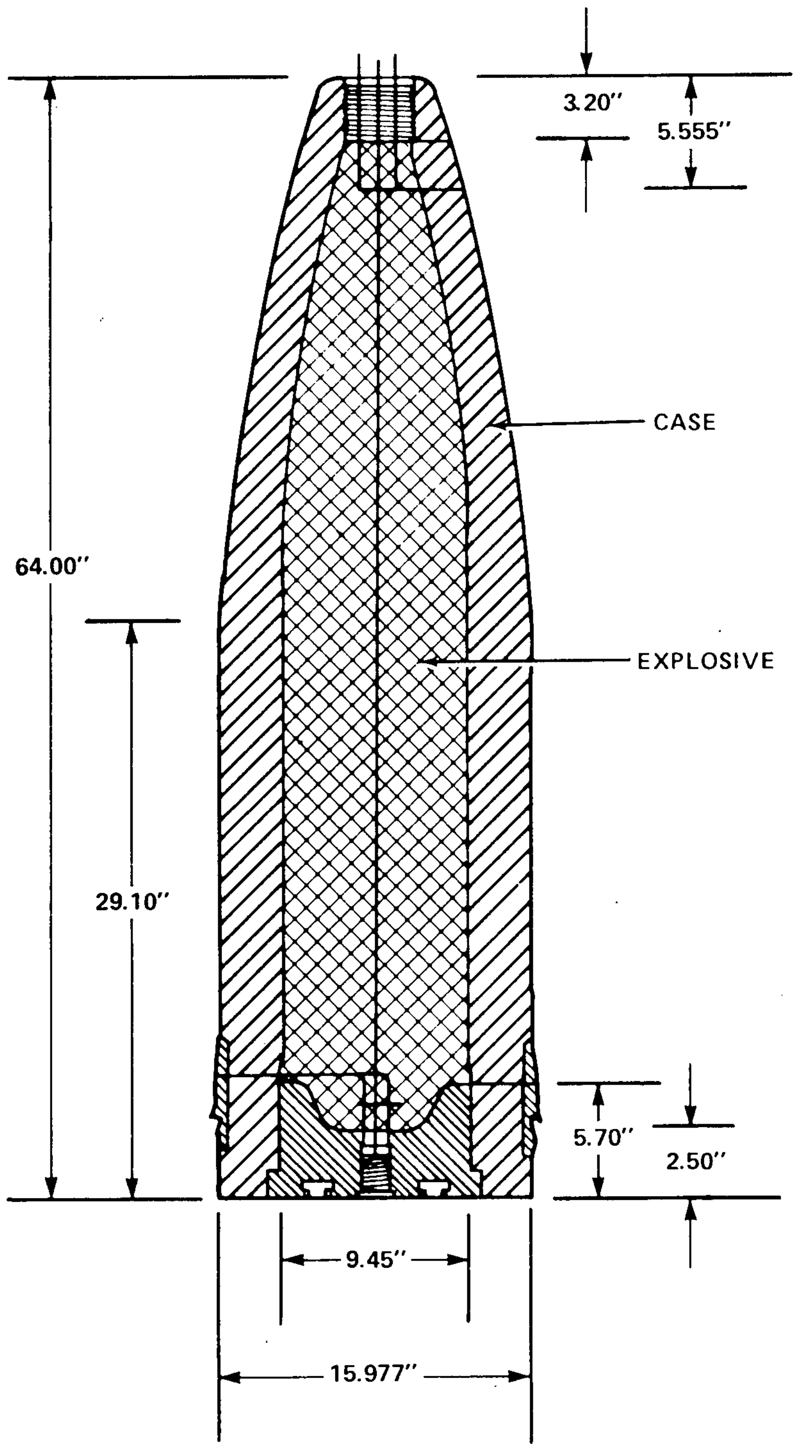
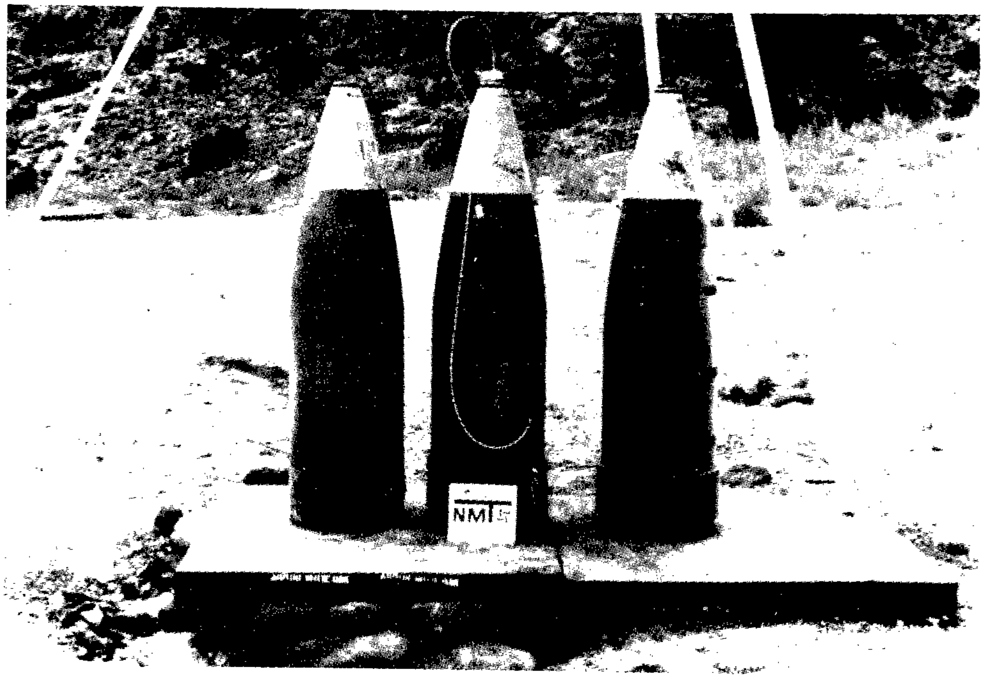


FIGURE 2. SINGLE-ROUND SYMPATHETIC DETONATION TEST ARRANGEMENT



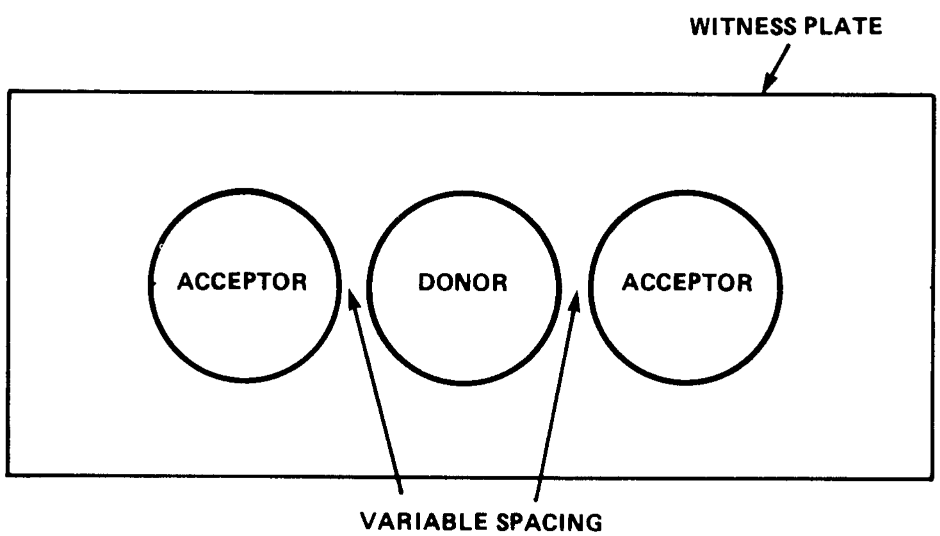
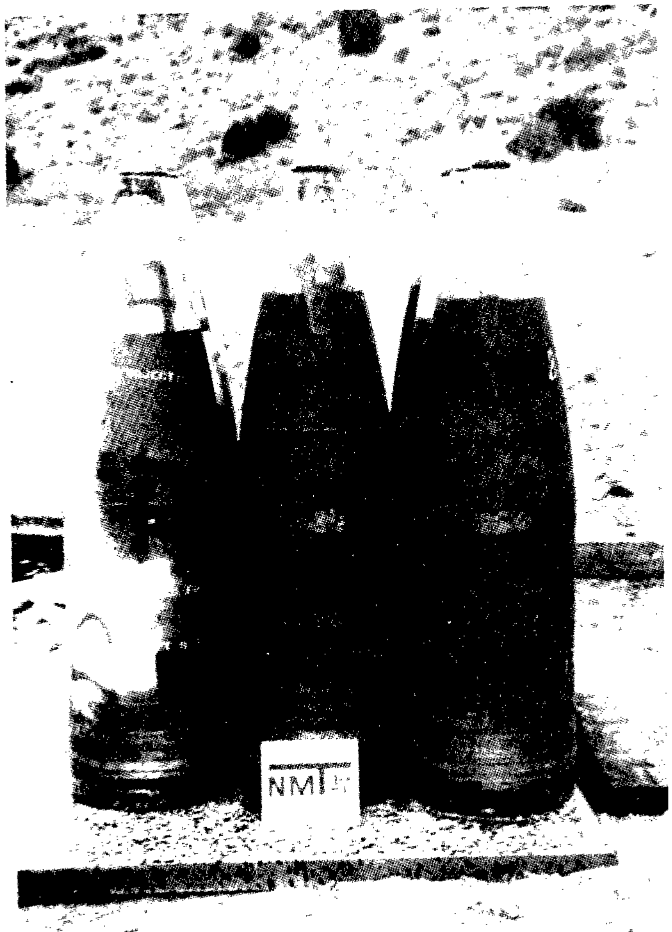


FIGURE 3. NINE-PROJECTILE TEST ARRANGEMENT



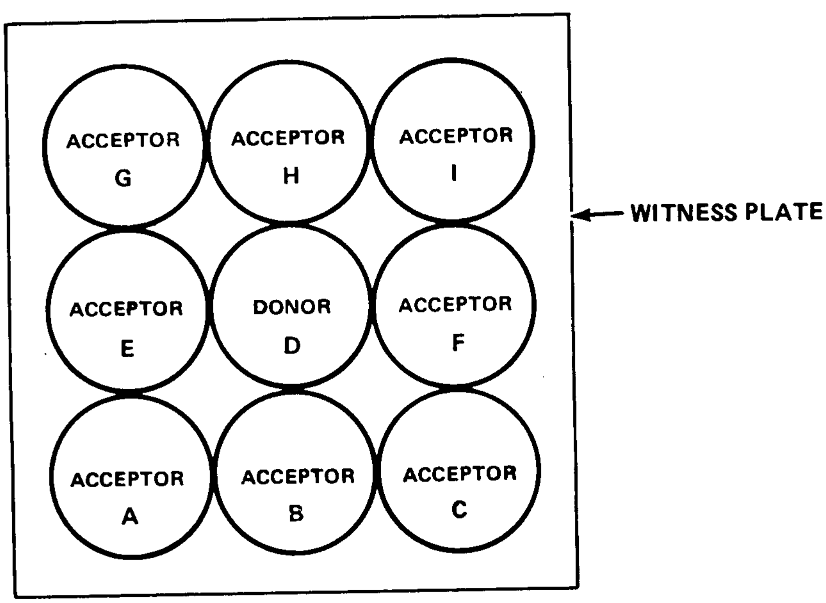
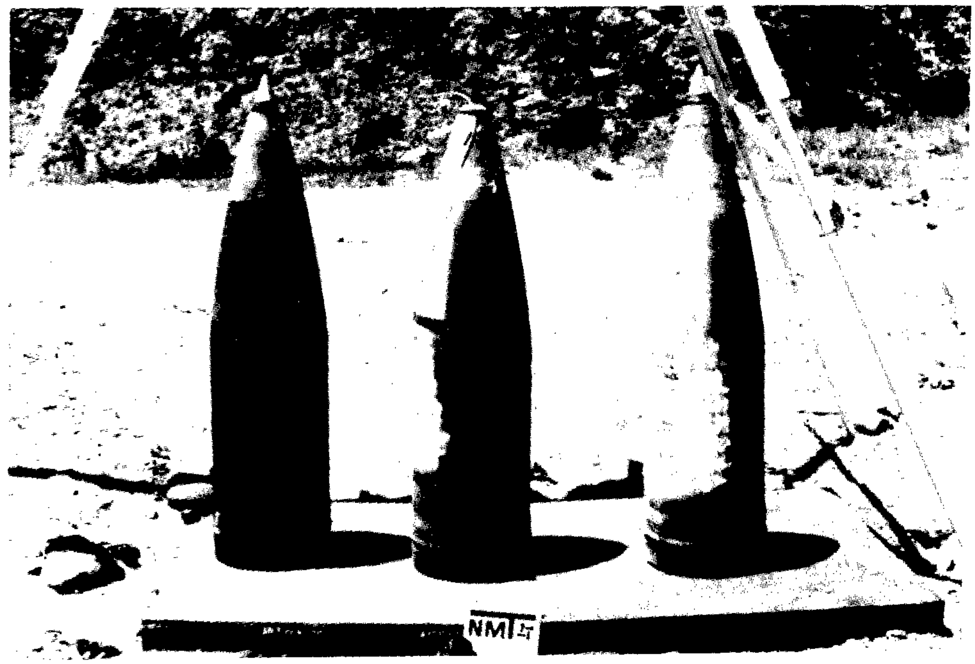
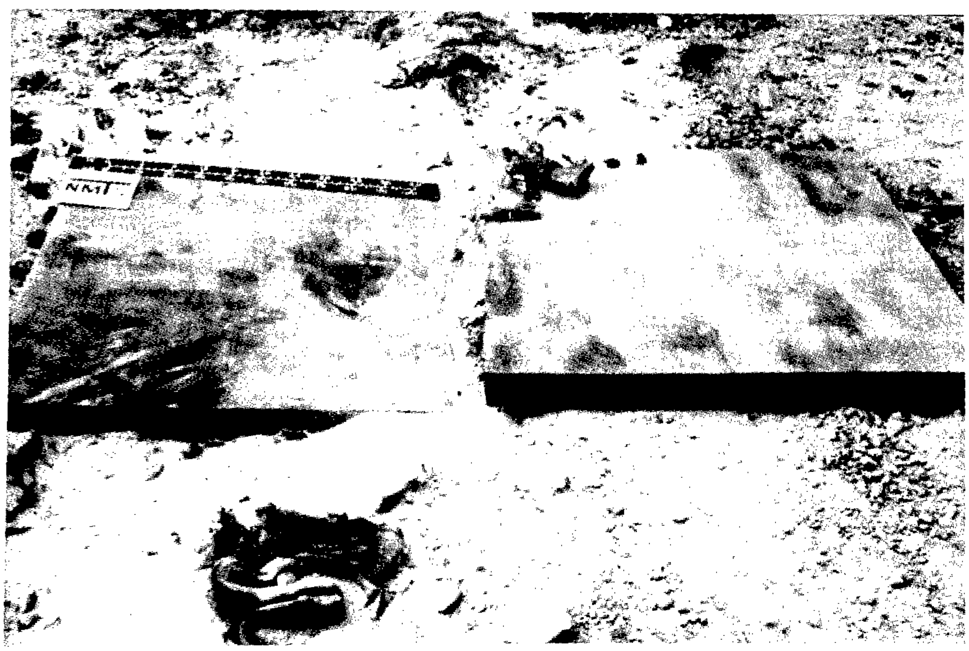


FIGURE 4. BEFORE AND AFTER – SYMPATHETIC DETONATION TEST



BEFORE



AFTER

FIGURE 5. PROJECTILE MAP FOR SHOTS 2097–2101

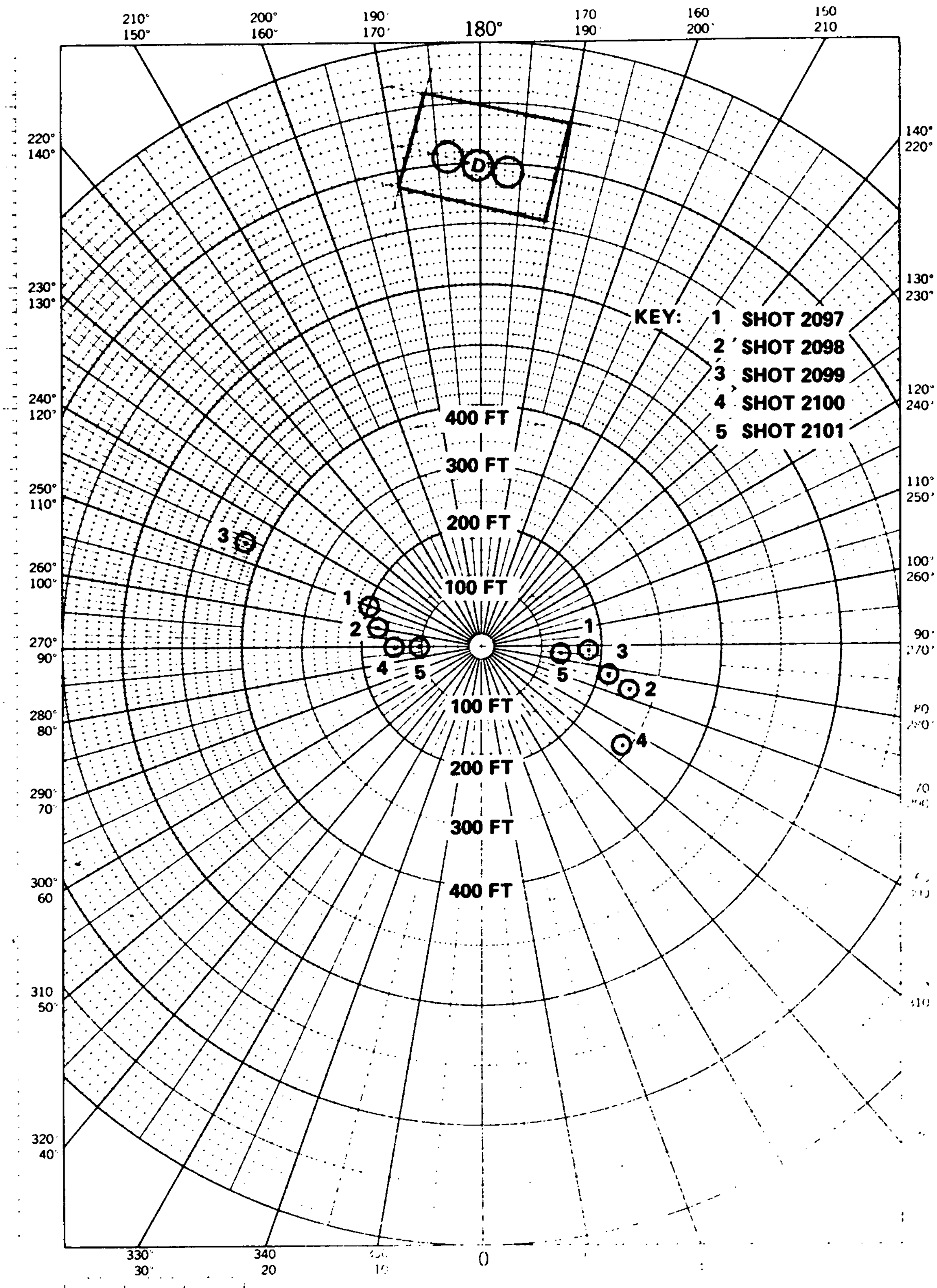
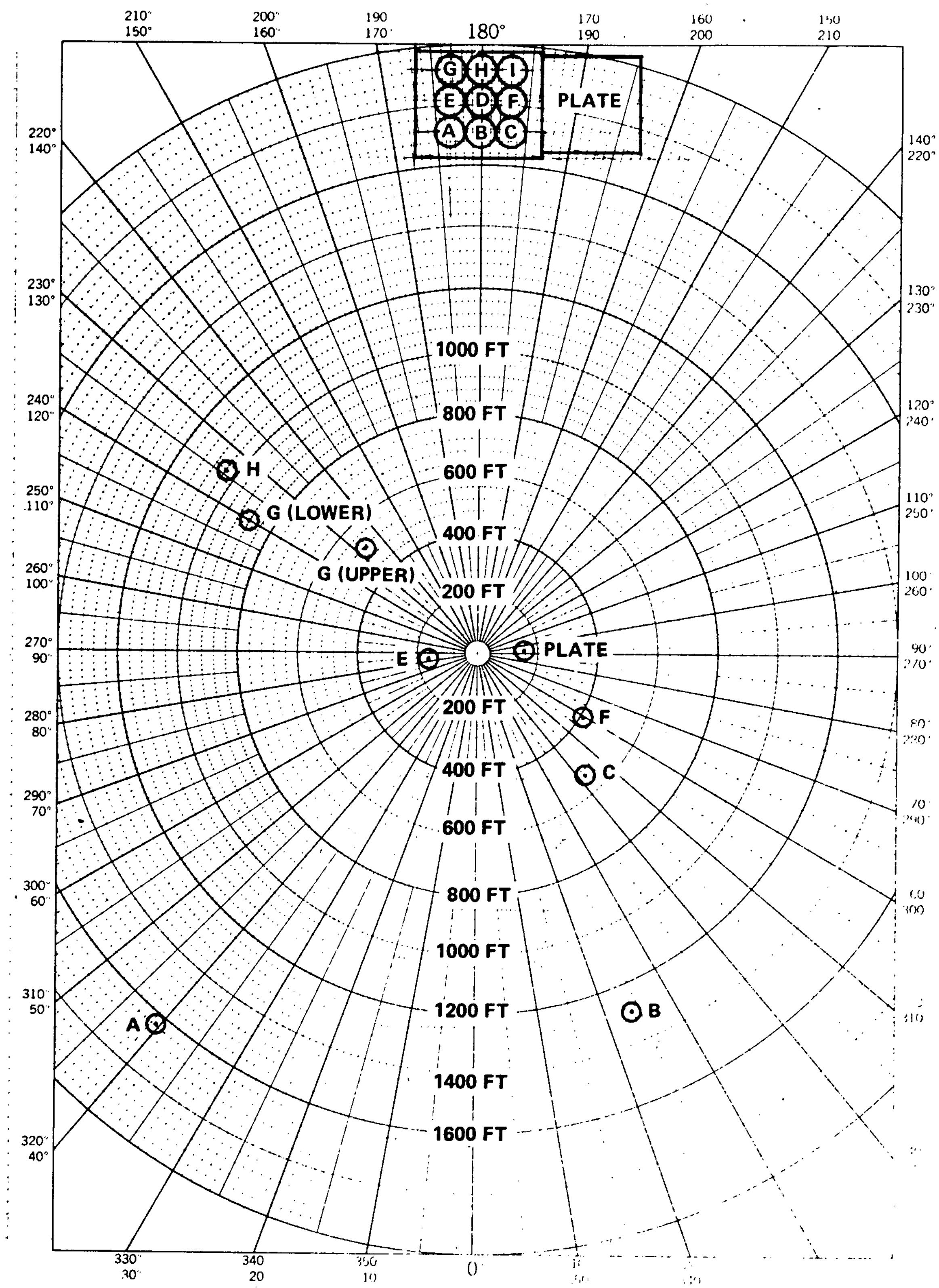


FIGURE 6. PROJECTILE MAP FOR SHOT 2102



PREFORMED FRAGMENT WARHEAD RECOVERY TESTS

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ABSTRACT

A series of preformed fragment warheads were designed and constructed. Each fragment was labeled so as to identify the warhead number and the column/row location of each fragment on the warhead. Single and multiple (simultaneous) warhead firings were conducted. Fragment initial velocities and beam spray were measured. The fragments were recovered, identified, and their impact locations were surveyed. Trajectory calculations are compared with fragment recovery results. The prediction of fragment enhancement in the vicinity of the maximum impact range is born out by the test results.

INTRODUCTION

OBJECTIVE

Determine the areal fragment distribution for a generic preformed fragment warhead and compare these results with the predictions made by the computer program TRAJ.[1]

BACKGROUND

All programs for the development and introduction of new weaponry into the Fleet are required to include analyses developed by the Naval Explosives Safety Improvement Program (NESIP). NESIP has, as one of its objectives, the examination of Naval munitions, in the small quantities handled on Naval waterfronts, and the several explosive handling scenarios which are experienced, to determine fragment and blast hazard ranges. The ultimate goal is the reduction of explosive-safety quantity-distance (ESQD) arcs which must be applied to small quantity handling evolutions. These define the basic scope of the program. The program deals with handling scenarios: transportation, loading, topping off, etc. It is also generally limited to small quantities of munitions. Small in the context of transportation and handling scenarios generally means no more than 1500 pounds Net Explosive Weight (NEW).

In essence then, each Naval munition or weapon system must be examined to answer the following questions:

1. Given the detonation of one round, what are its effects on any surrounding rounds? Will the surrounding ordnance sympathetically detonate? What is the Maximum Credible Event (MCE)?

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[1]Porzel, F. B., "Technology Base of the Navy Explosives Safety Improvement Program," Minutes of the Nineteenth Explosives Safety Seminar, Department of Defense Explosives Safety Board, Los Angeles, CA, Sep 1980.

2. For the MCE, and applying the Department of Defense Explosives Safety Board (DDESB) standards, what is an appropriate ESQD arc?

The approach has been two-fold; analytical and experimental. Predictions are made using the analytical techniques developed for this program. These predictions are then verified, as needed, experimentally. When the theory is inadequate, it is developed/refined and experimental tests are conducted to determine relationships from the data. The analytical techniques form the NESIP Technology Base, which was described by Porzel[1] at the 1980 DDESB seminar. As the results of these analyses and predictions were compared with the experimental data, it became clear that less testing would be required. In every case to date in which differences did occur between the Technology Base predictions and the experimental results, the Technology Base was found to be more conservative (i.e., required a larger ESQD arc).

One analytical tool in the Technology Base used for determining fragment hazard ranges is the computer program TRAJ.[1] TRAJ is a two-degree-of-freedom particle model program which calculates the trajectory of an individual fragment, given the fragment parameters, initial conditions, and ambient conditions.

The detonation of any warhead produces fragments of varying initial velocity, area, and mass. In general, the fragment initial conditions used are those for a fragment with an average mass and area and the maximum initial velocity. The maximum initial velocity is used to obtain the worst case condition for impact range. The reason for not using the maximum value for fragment mass (and associated area) is that the results should be conservative, but not overly so. The initial input conditions for TRAJ are obtained from warhead design and arena test data.

In 1982, Ward and Lorenz[2] described trajectory calculations and fragment range predictions made for a generic preformed fragment warhead using the computer program TRAJ. These calculations indicated that 18% of the fragments would impact within 100 feet of their maximum range--a significant effect which could have a major influence on the number of warheads allowed for safe handling, based on their fragment hazard arc. This effect is shown in Figure 1, reproduced from reference (2). Questions were raised as to whether or not this was a real effect, or an artifact of the computer calculations. The answer to these questions had to be determined experimentally.

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[2] Ward, Dr. Jerry M. and Lorenz, Richard A., "SPARROW (AIM/RIM-7M) with EX-114 MOD 1 Warhead Quantity-Distance Study for Handling Operations," Minutes of the Twentieth Explosives Safety Seminar, Department of Defense Explosives Safety Board, Norfolk, VA, August 1982.

EXPERIMENTAL PROGRAM

PROGRAM ELEMENTS

Predictions. Estimates of maximum fragment ranges were prepared in order to determine the fragment size and initial velocity to be used for the tests.

Several requirements were placed on the warhead design, and these limited the cases considered in the initial predictions. Some of these requirements included:

(1) The fragments must be rectangular parallelopipeds.
(2) The fragments must be large enough to be readily visible for ground pickup.
(3) The maximum fragment range should be approximately 1200 feet (to allow for recovery on the test pad).

Table 1 lists the initial predictions.

Warhead Fabrication. Based on these requirements and predictions, warheads were designed and fabricated by New Mexico Institute of Mining and Technology, TERA Group. Each warhead contained 36 columns of 22 rows. The first six warheads utilized steel fragments with dimensions of 1 in. X 1 in. X 0.25 in. The next six warheads contained steel fragments with dimensions 1 in. X 1 in. X 0.188 in. All fragments were epoxied inside an outer skin of 0.0312 in. steel. Fragments were stamped with numbers and letters indicating their column and row positions as well as the warhead number. A schematic of the warhead design is shown in Figure 2.

Field Setup. The tests were conducted at the West Valley test area of the TERA facility, Socorro, New Mexico. Surveys were made to establish the zero-degree recovery line. The warheads were boosted on one end; thus, the recovery area was offset by 7^{o} from the normal of the warhead axis to account (estimated) for the fragment beam spray ejection angles. Each warhead was placed in a horizontal orientation on a five and half foot high stand with the stamped fragments oriented towards the recovery area.

Fragment initial velocities and beam spray angles were determined by the use of flash panels and high speed photography on each shot (basically an arena test setup). A schematic of the field set-up is shown in Figure 3.

After each test series, each fragment was surveyed in place, collected, and analyzed.

The firing program consisted of firing twelve preformed-fragment warheads for the purpose of collecting fragment-distribution data. Each warhead contained a two inch booster of C-4 explosive and a main charge explosive of either C-3 or powdered TNT. Table 2 describes the twelve warheads in more detail and gives the nominal purpose of each test.

Although not originally planned as such, the first six events became warhead design verification shots, with the last four events to be used for detailed prediction comparisons. The last event involved the simultaneous detonation of three warheads, testing the effects of shielding: Does the

detonation of three warheads yield three times the number of fragments in the recovery area as from the detonation of a single warhead, or does the closer warhead to the recovery area shield the recovery area from the other two warheads?

RESULTS

A preliminary survey of the fragments on the recovery pad, after the first two events, indicated that only a small number of fragments actually landed on the recovery pad (most went beyond). Thus, for the third test, the C-3 explosive main charge was replaced with powdered TNT to reduce the fragment initial velocities to a level such that a greater percentage of the fragments would impact on the recovery area. A preliminary survey after the third test indicated that a sufficient number of fragments were landing on the recovery arena. An analysis of the measured fragment velocities indicated that, indeed, the velocities had been reduced to the desired level. Powdered TNT was used for main charge explosive for the remaining events.

Examination of the fragment velocity data presented in Table 2 shows a wide spread in the measured velocity data for the first six events--indicative of problems associated with the warhead design. Events 7-10 had a much narrower velocity spread. The remainder of this paper will concentrate on a discussion of the results for these last four events. The warhead fragments for Events 7-10 were somewhat smaller in mass (24 gm) then those used in Events 1-6 (32 gm) as an additional measure for reducing the range of the fragment impacts.

Figure 4 is a plot of the impact locations for Events 7, 8, and 9. Several features are apparent from a study of this feature:

(1) The reproducibility from event-to-event is good
(2) It appears that there is a clustering at, or near, the fragment maximum range (though certainly not in the farthest 100 feet increment of range)
(3) The fragment maximum range is not a well-defined cut-off
(4) Significant numbers of fragments appear outside the near-field arena-defined beam spray.

Based on the fragment description presented in Table 2, and the warhead descriptions presented in Figure 2, revised predictions of fragment number versus range can be made. These are shown in Figure 5a; shown on Figure 5b are the percentage of experimentally recovered fragments as a function of range. As can be seen, the predicted percentages of fragments versus range are in good agreement. However, looking at the results in another way, the agreement is not as good. If one considers areal density of fragments versus range, a similar comparison of predicted versus experimental/results can be made. Such a comparison is shown in Figure 6. The prediction over-estimates the peak areal density by a factor of 2.5 on the side of conservatism.

The test results provide evidence for several mechanisms for insuring that the predicted results should be conservative (overestimate the hazard range and areal densities). Some of these mechanisms were expected, some were not. The expected mechanisms include distributions for initial velocities, shapes, and orientations (some fragments were re-shaped upon impact; each of

the fragments has a somewhat different orientation-time history during its flight). Unexpected mechanisms include appreciable numbers of fragments located outside the beam spray area (fragments were surveyed in at unexpected locations based on their initial positions and ejection angles). Analysis of these test results are continuing.

The effects of warhead shielding are very evident in the fragment recovery data presented in Table 3. Events 7, 8, and 9 all had comparable numbers of fragments recovered. Only warhead 10 of Event 10 (the outer warhead, closest to the recovery area) produced similar numbers. Very few fragments from warheads 11 and 12 made it onto the recovery pad. It also appears that the average fragment ranges for Event 10 were somewhat less than those on Events 7, 8, and 9. This difference could be real, but the result is based on only one test (Event 10), and a statistical aberration cannot be ruled out. These differences are shown in Table 4.

Another phenomenon was noted during these tests. In several instances, fragments located 180^{0} away from the recovery area were found on the recovery pad. Moreover, fragments from warhead columns which should have impacted the ground at ranges near ground zero were found at ranges over 1000 feet from ground zero. This is shown in Table 5. Column 9 represents fragments projected in a downward direction (see Figure 2). Both of these examples can be explained by fragment ricochet off the ground. (Similar effects are addressed in another paper at this Symposium).[3]

Table 5 also shows the number of fragments collected from each column and compares the predicted number with the measured ranges from these tests.

FINAL DISCUSSION

The "bunching" of preformed fragments in the vicinity of the maximum impact range predicted by earlier work[2] does, indeed, occur, as verified by this experimental program. The percentage of collected fragments as a function of range can be predicted quite well. Less accurate, although still conservative, are estimates of fragment areal density as a function of range. The close-in beam spray (as determined by arena tests) does not adequately describe the far-field fragment pattern.

When considering multiple warhead detonations, shielding effects of interior warheads must be taken into account. Only those warheads with a direct line of sight to the recovery area appear to contribute to the fragment hazard. This shielding effect has been reported by other investigators[4] though this is the first time experimental data have been collected that correlate the initial conditions and fragment locations with the final impact locations.

[3]McClesky, F., "Fragmentation Hazard Computer Model," Minutes of the Twenty-First Explosives Safety Seminar, Department of Defense Explosives Safety Board, Houston, TX, August 1984.

[4]Ramsey, R. T., Powell, J. G., and Smith, III, W. D., "Fragment Hazard Investigations Program," Minutes of the Eigtheenth Explosives Safety Seminar, Department of Defense Explosives Safety Board, San Antonio, TX, Sep 1978.

TABLE 1 COMPUTED IMPACT RANGES (FEET) FOR PREFORMED FRAGMENT DESIGN OPTIONS

Fragment Size (WxLxT-inches)	Initial Velocity of Fragment (ft/s)* 6500	5500	4500	3500	2500
1x1x0.25	1317	1278	1229	1172	1096
0.75x0.75x0.25	1317	1278	1229	1172	1096
0.6x0.6x0.25	1314	1273	1224	1165	1096
0.5x0.5x0.25	1317	1278	1229	1172	1096
0.75x0.75x0.25**	602	585	566	542	511
0.5x0.5x0.25**	602	585	566	542	511
1x1x0.2	1094	1062	1023	976	976
0.75x0.75x0.2	1094	1062	1023	976	976
0.6x0.6x0.2	1094	1062	1023	976	976
0.5x0.56x0.2	1094	1062	1023	976	976
0.75x0.75x0.2**	499	485	469	450	425
1x1x3/16	1037	1007	970	926	868
0.75x0.75x3/16	1037	1007	970	926	868
0.6x0.6x3/16	1037	1007	970	926	868
0.5x0.5x3/16	1037	1007	970	926	868
0.75x0.75x3/16+	1262	1224	1178	1123	1051
0.5x0.5x3/16+	1262	1224	1178	1123	1051
1x1x0.25+	1600	1550	1495	1417	1320

*Calculations were done using a shape factor of 0.8

**Calculations were done using a shape factor of 0.33

+Calculations were done using a shape factor of 1.0

TABLE 2 FIRING PROGRAM

Event	Warhead Number	Fragment Size	Explosive	Beam Angle	Velocity (ft/s)	Purpose
1	1	1x1x0.25	C-3	9.8	5630-6100	W/H* Development
2	4	1x1x0.25	C-3	6.0	4250-5450	W/H Development
3	2	1x1x0.25	Powdered TNT	5.1	2330-5050	W/H Development
4	5	1x1x0.25	Powdered TNT	5.2	2450-5900	W/H Development
5	6	1x1x0.25	Powdered TNT	5.5	2300-5430	W/H Development
6	3	1x1x0.25	Powdered TNT	5.2	2460-5380	W/H Development
7	7	1x1x0.188	Powdered TNT	15.0	5000-6720	Verification
8	8	1x1x0.188	Powdered TNT	15.0	5000-6720	Verification
9	9	1x1x0.188	Powdered TNT	15.0	5000-6720	Verification
10	10,11,12	1x1x0.188	Powdered TNT	10.0+	5000-5940	Multiple W/H

*W/H stands for warhead

+Estimate

TABLE 3 NUMBER OF FRAGMENTS RECOVERED

EVENT	NUMBER OF FRAGMENTS RECOVERED
7	69
8	113
9	88
10-10*	88
10-11	5
10-12	3

*Event-warhead number

TABLE 4 AVERAGE FRAGMENT RANGES

COLUMN	AVERAGE RANGE (feet)	
	Events 7,8,9	Event 10
9	1137	1062
10	1147	1243
11	1191	1080
12	1180	1019
13	1097	883
14	960	761
15	833	728
16	683	390
17	436	176
18	344	41

TABLE 5 PREFORMED FRAGMENT RANGES

EVENTS 7 TO 9

Column	Number of Fragments Collected	TRAJ Maximum Range (ft) (6720 ft/s)	TRAJ Minimum Range (ft) (5000 ft/s)	TEST RESULTS Average Range (ft)	TEST RESULTS Maximum Range (ft)	TEST RESULTS Minimum Range (ft)
9	16	N/A	N/A	1137	1508	819
10	44	1140	1060	1147	1430	924
11	47	1260	1190	1191	1485	906
12	32	1250	1190	1180	1466	928
13	30	1180	1120	1097	1409	845
14	30	1050	1010	960	1535	691
15	25	890	850	833	1234	435
16	23	670	640	683	1186	456
17	8	420	410	436	1093	234
18	8	150	140	344	1011	97

EVENT 10

Column	Number of Fragments Collected	TRAJ Maximum Range (ft) (5940 ft/s)	TRAJ Minimum Range (ft) (5000 ft/s)	TEST RESULTS Average Range (ft)	TEST RESULTS Maximum Range (ft)	TEST RESULTS Minimum Range (ft)
9	12	N/A	N/A	1062	1394	394
10	14	1110	1070	1243	1450	886
11	15	1230	1190	1080	1300	887
12	15	1230	1190	1019	1270	876
13	10	1160	1120	883	1037	721
14	8	1030	1010	761	1115	505
15	3	870	850	728	1025	480
16	8	660	640	390	855	122
17	1	420	410	176	---	---
18	1	150	140	41	---	---

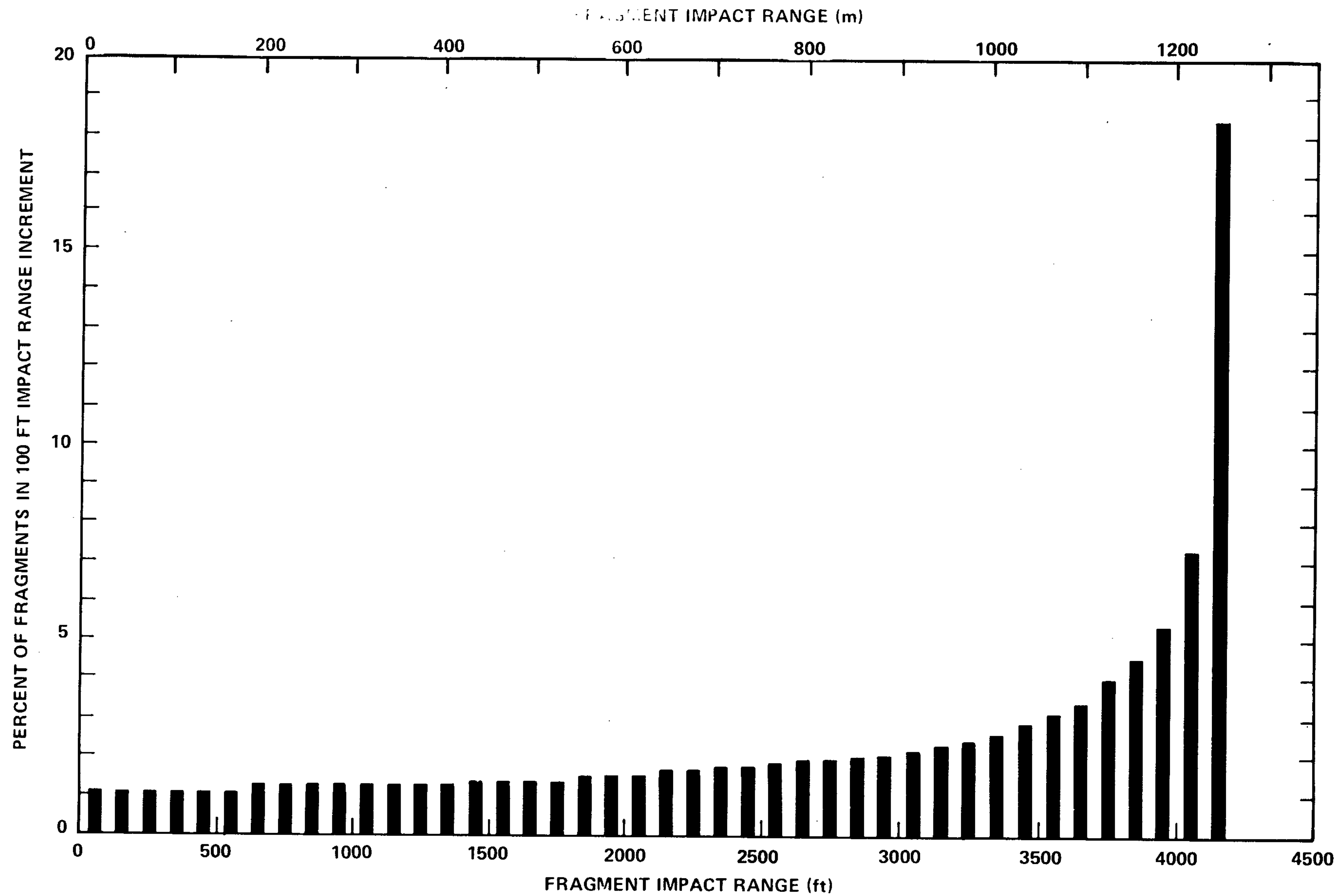

FIGURE 1 PERCENT OF FRAGMENTS IMPACTING WITHIN 100 FT RANGE INCREMENT

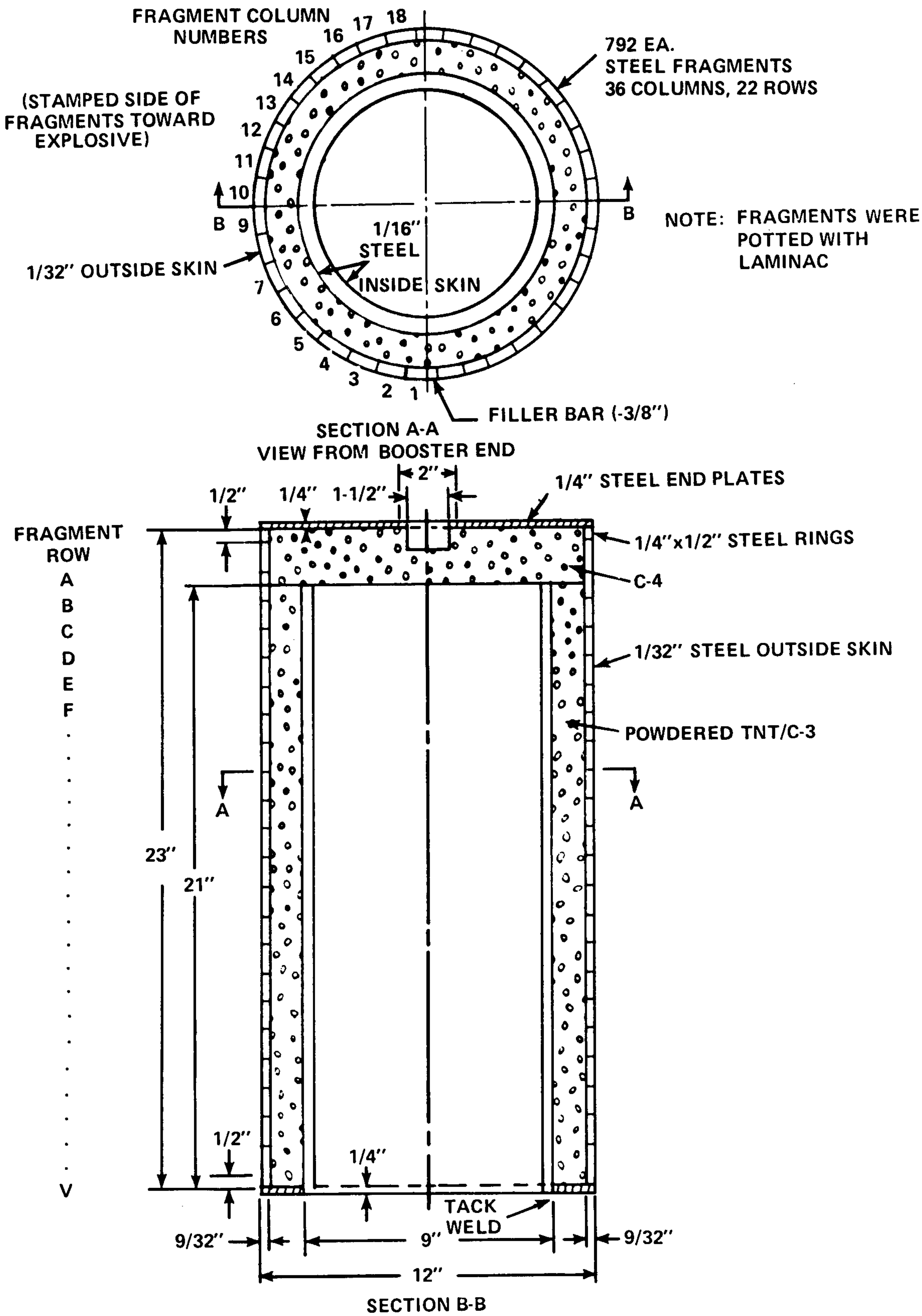

FIGURE 2 WARHEAD DESIGN

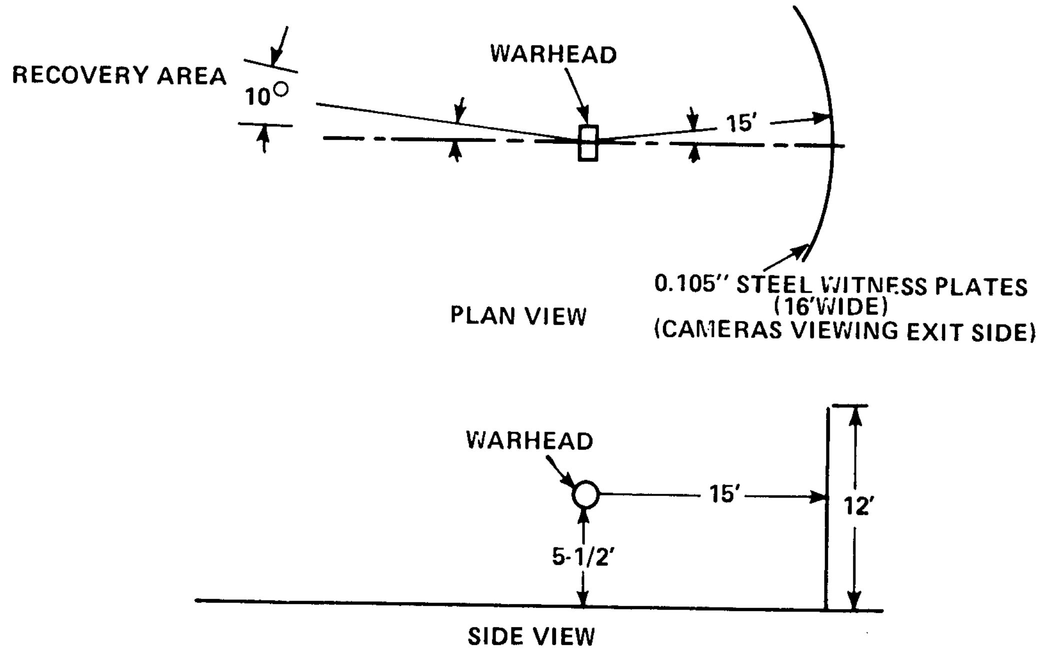

FIGURE 3A TEST ARENA FOR FRAGMENT RECOVERY TEST

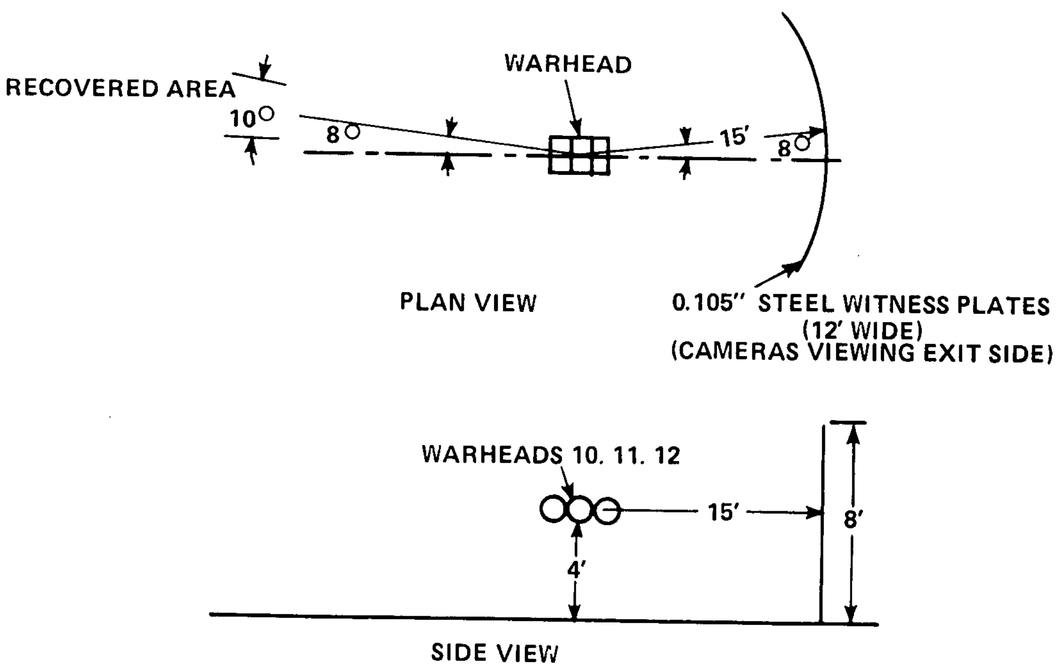

FIGURE 3B TEST ARENA FOR FRAGMENT RECOVERY TEST FOR MULTIPLE WARHEAD TEST

FIGURE 3 FIELD ARRANGEMENT

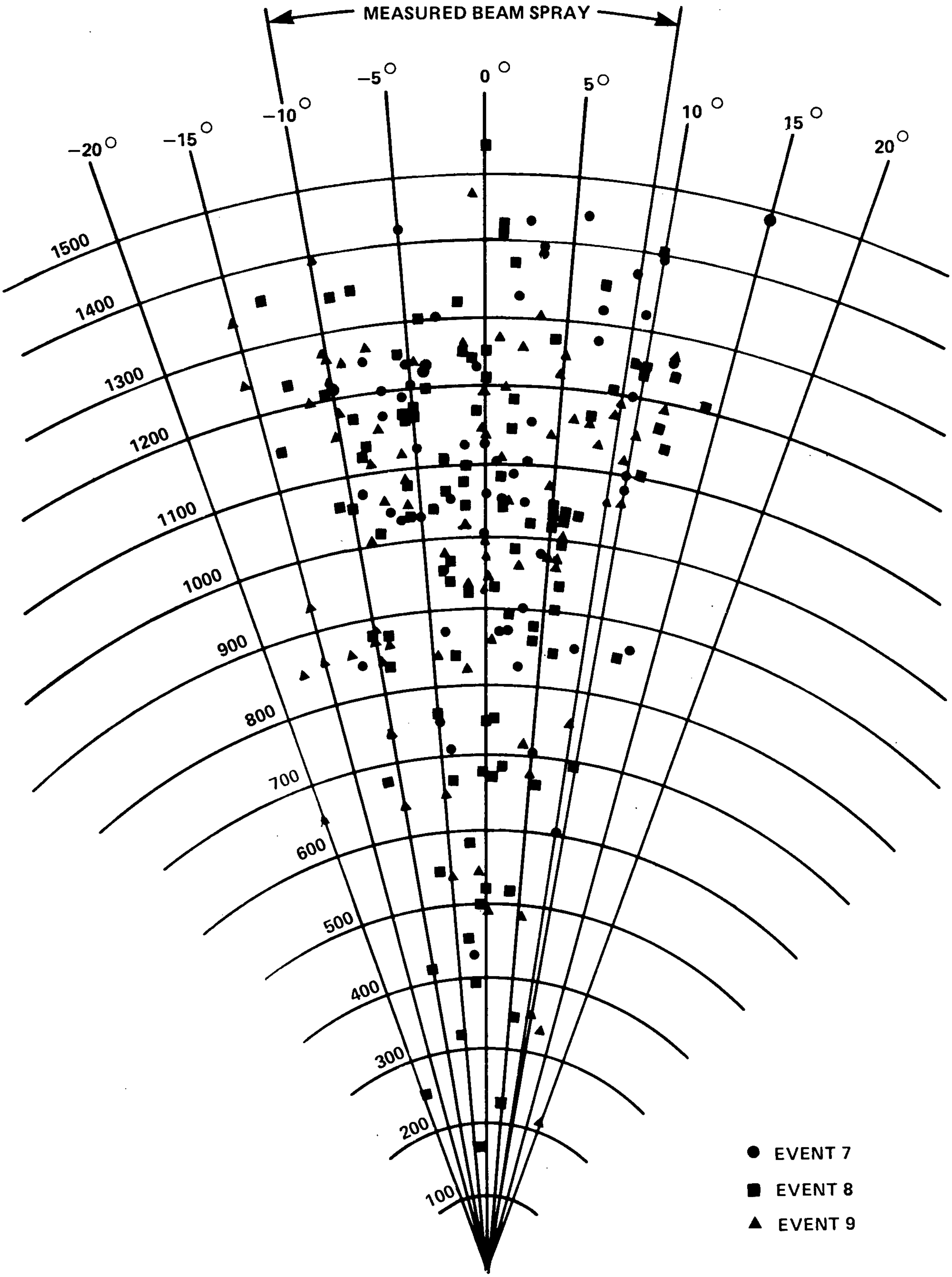

FIGURE 4 FRAGMENT RECOVERY DATA

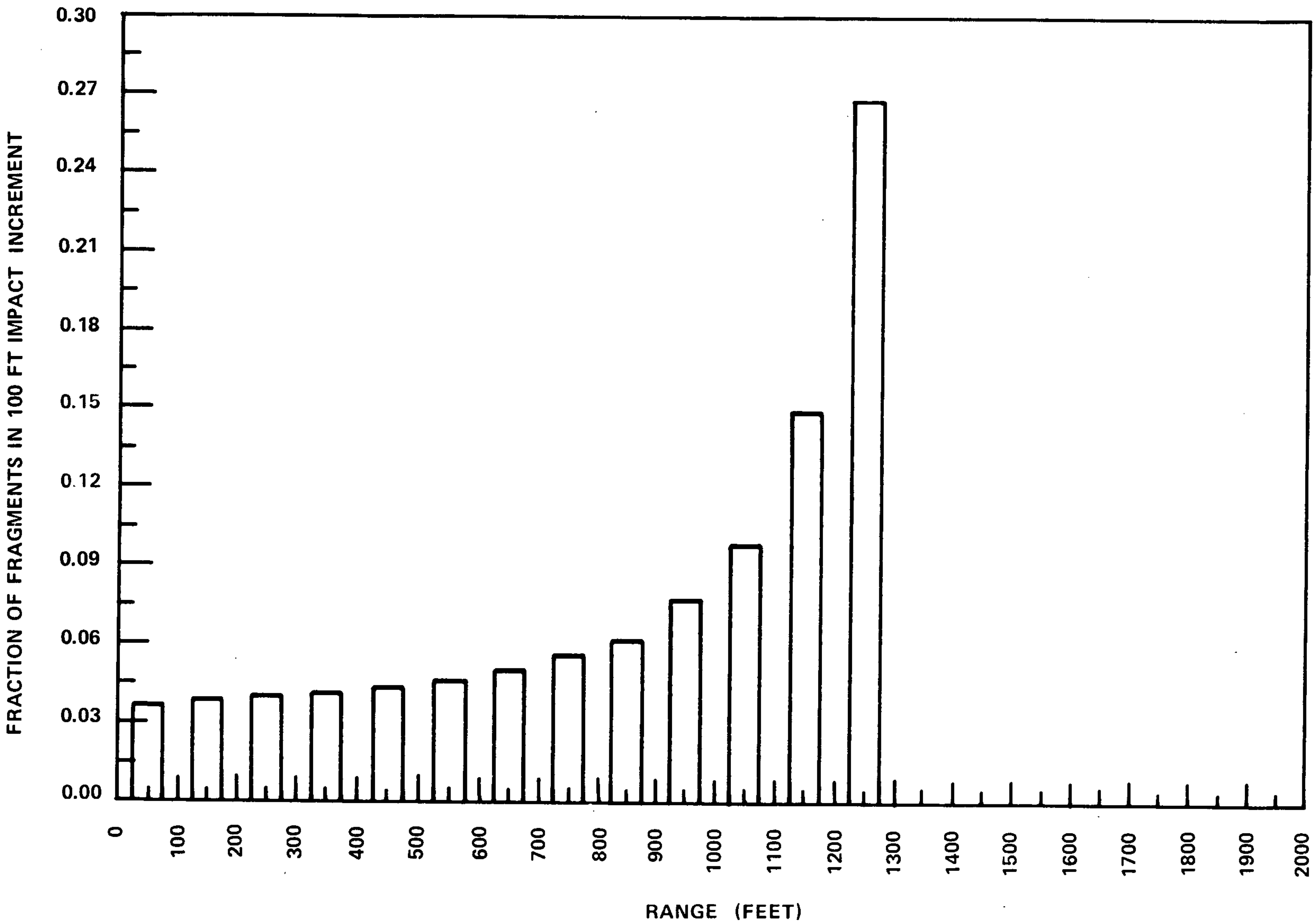

FIGURE 5A PREDICTED FRAGMENT DENSITY DISTRIBUTION

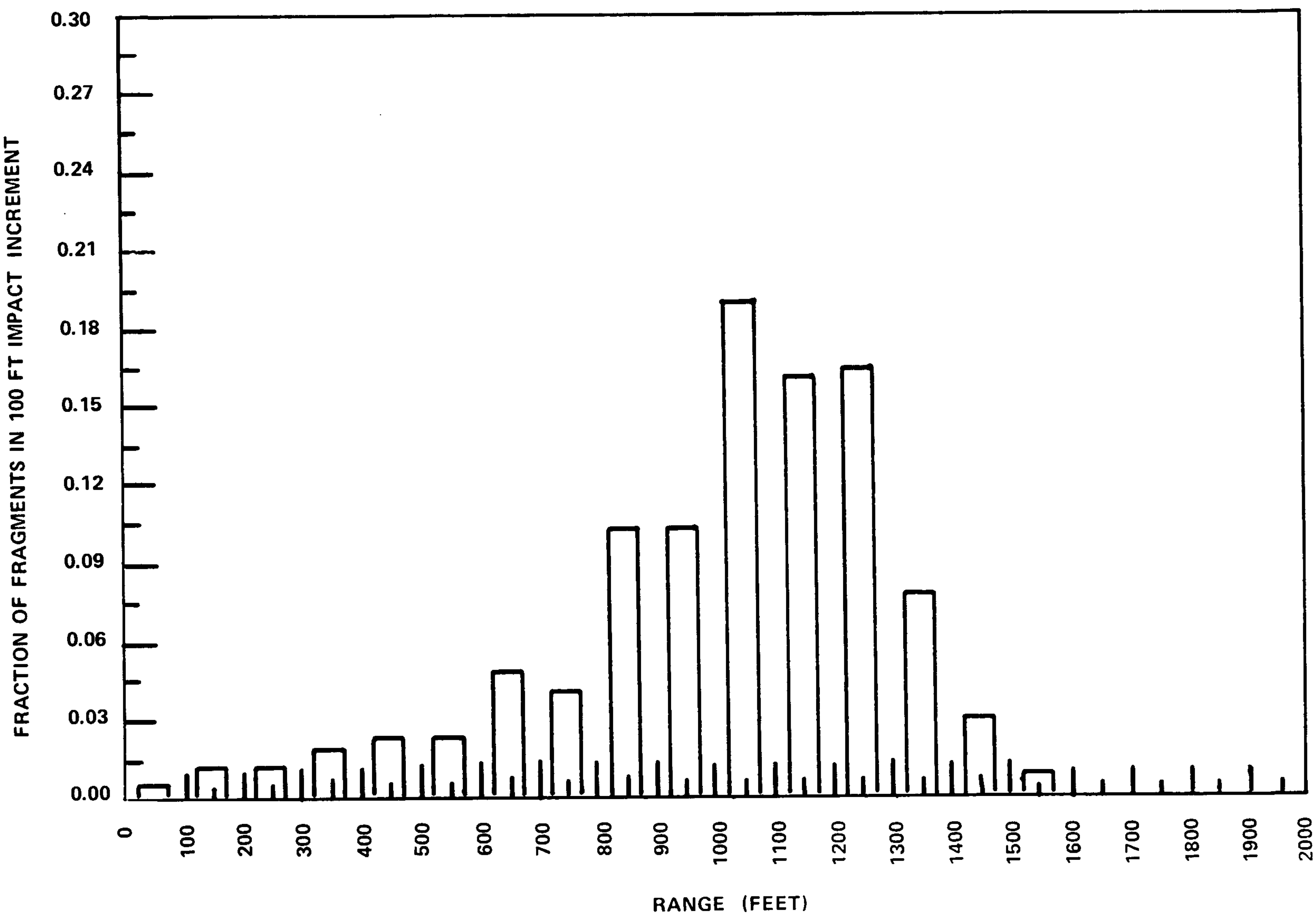

FIGURE 5B MEASURED FRAGMENT DENSITY DISTRIBUTION

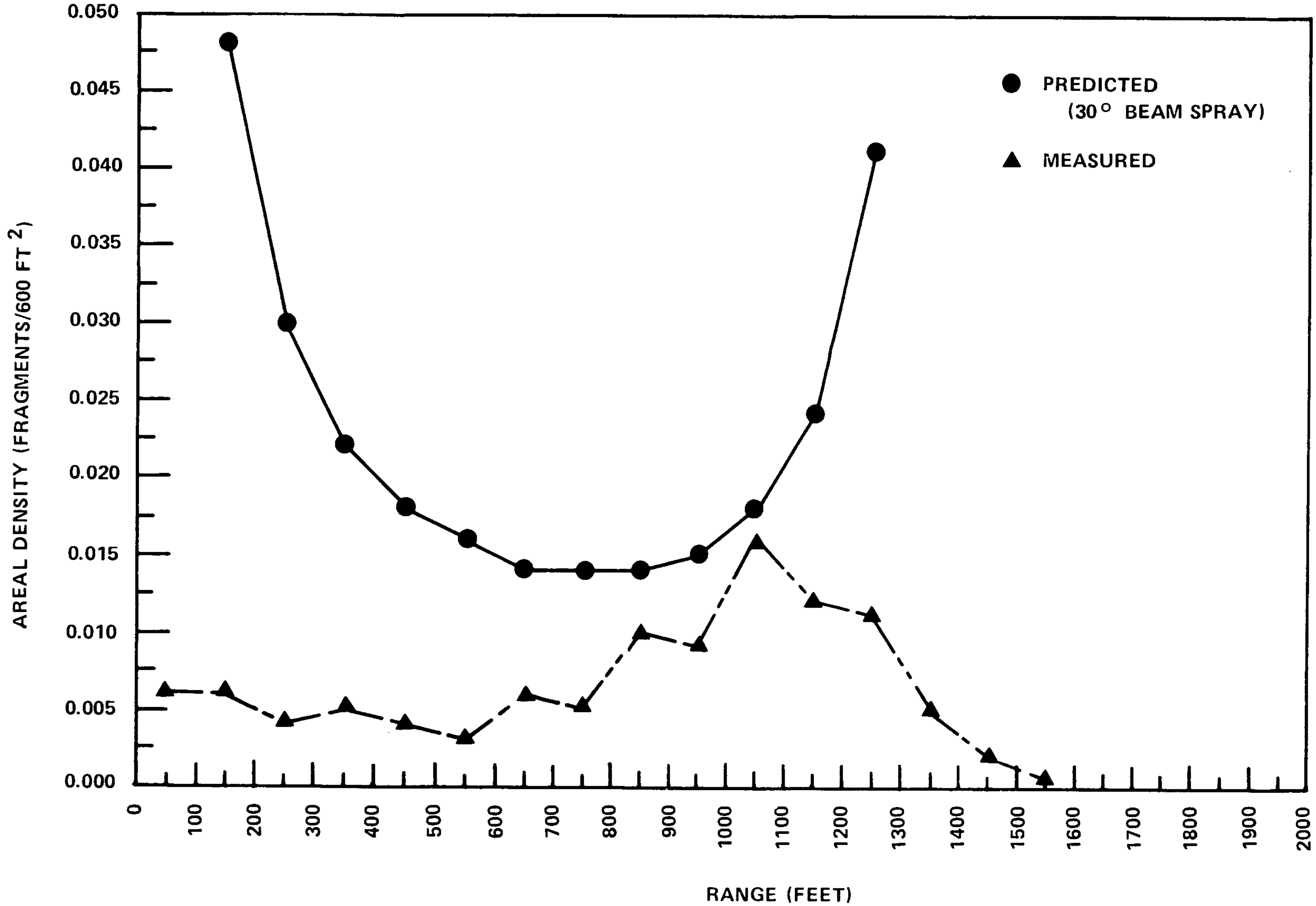

FIGURE 6 AREAL DENSITY VERSUS RANGE

MAXIMUM TNT EQUIVALENCE OF NAVAL PROPELLANTS

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ABSTRACT

As part of the Naval Explosives Safety Improvement Program (NESIP), two series of tests have been conducted to determine the maximum TNT equivalence of Naval propellants. Airblast and detonation velocity measurements were made on M26 and NACO 5-inch propelling charges, MK 10 (3.25"), MK 16 (5"), MK 40 (2.75"), MK 58 (SPARROW), MK 37 (ASROC), MK 27 (TARTAR), MK 30 (STANDARD) rocket motors, and TNT cylinders. The MK 40 and MK 37 motors detonated high order and had a TNT equivalence of 70-75%. The other propellants had TNT equivalencies ranging from 5 to 50%. Recommendations are also made about possible revisions to OP-5. Instead of the 25 percent equivalency now used for guided missile propellants, 100 percent is recommended for double base and composite/double base materials, 50 percent for composite materials, and 125 percent for high energy propellants.

INTRODUCTION

Other studies have shown that solid propellants can detonate, and, even if not detonating, can be made to react rapidly enough to have a significant explosive yield. If this is the case, then many solid propellants and the devices utilizing them could have significant TNT equivalencies.

Current Navy practice, as stated in Navy publication OP-5 (Ammunition and Explosives Ashore: Safety Regulations for Handling, Storing, Production, Renovation, and Shipping)[1] is to basically ignore propellant contributions to the determination of New Explosive Weight (NEW) (with the exception listed below).

OP-5 states in Section 5-3.2 (Basis for Q-D Determinations and Computations):

"For shore stations . . . the net weight of explosives for each type of ammunition item shall be computed as follows . . .

> Fixed Ammunition - The net weight of the explosives in the projectile or warhead; the smokeless powder in the cartridge case is disregarded in this instance.
>
> Rocket Warheads and Motors packed together (Assembled or Unassembled) - the net weight of the explosives in the rocket warhead; the propellant is disregarded.
>
> Guided Missiles - the net weight of the explosive in the warhead plus 25 percent of the propellant weight of the motor.

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[1] Ammunition and Explosives Ashore: Safety Regulations for Handling, Storing, Production, Renovation and Shipping, NAVSEA OP-5 Vol. I, revision 11, 15 May 1983.

On board ship, the explosives and ammunition are stowed relatively close to each other and a detonation in the mass-detonating part of the cargo would receive considerable support from categories that are normally considered to be fragment or fire hazards.

Accordingly, the total quantity of mass-detonating explosives may be calculated by using the weight of HE filler and the weighted values for different types of propellants and other fillers in relation to TNT. For a general approximation, use the total quantity of HE plus 25 percent of the propellant."

Several questions have been raised about this 25 percent equivalency factor for solid propellants. Some propellants, and even classes of propellants may not detonate nor even react violently; for these, the equivalency is close to 0. Others may react violently, but not sustain a true detonation; for these, the TNT equivalency is between 0 and 100 percent. Still others, especially the newer high energy propellants may behave like ideal explosives and detonate with a TNT equivalency greater than 100 percent.

To address this problem the Naval Explosives Safety Improvement Program (NESIP) has conducted a two-phase experimental program to determine the maximum TNT equivalency for several rocket motors and two gun propellant cartridges currently in the inventory. In addition, a literature search has been conducted on similar research efforts by other groups.

In order to determine a maximum TNT equivalency, actual missile motors or propellant cartridges were tested. The size of the explosive booster was chosen to nominally represent at least 10 percent of the total propellant weight. It was felt that this would represent a "worst case" condition which would yield a maximum equivalency.

EXPERIMENTAL PROGRAM

Several types of propellant were investigated--two gun propellants and five rocket propellants. The gun propellants were M26 and NACO, each contained in standard 5"/54 propellant cartridges. The rocket propellants considered were those contained in the following motors; (1) MK 58 SPARROW, (2) MK 37 ASROC, (3) MK 30 STANDARD sustainer, (4) MK 27 Improved TARTAR, (5) MK 16 5" ZUNI, (6) MK 40 2.75" MIGHTY MOUSE, and (7) MK 10 3.25". These were fired in two phases: items (1) - (3) and the gun propellants in Phase I, and items (4) - (7) in Phase II.

NACO is primarily nitrocellulose (with stabilizers) and represents single base gun propellants. M26 is nitrocellulose, nitroglycerine, and stabilizers and represents double base gun propellants.

The MK 58 SPARROW motor is composed of ammonium perchlorate, aluminum, and a rubbery binder. The MK 30 STANDARD propellant is composed of ammonium perchlorate and a rubbery binder. The MK 27 TARTAR propellant is composed of ammonium perchlorate/polyurethane/aluminum and ammonium perchlorate/nitroguanidine/polyurethane. The MK 37 ASROC, MK 40, and MK 10 MIGHTY MOUSE propellants were N5, and the MK 16 was X-8, all nitrocellulose, nitroglycerine, plus a binder.

The SPARROW, STANDARD, and TARTAR propellants were chosen to represent composite propellants; the MK 37, MK 40, and MK 16 were chosen to represent double-base propellants.

As part of the same program, TNT comparison charges were also detonated. Three sizes were used, corresponding to the three nominal propellant sizes. These charges were designed to have similar length-to-diameter (l/d) ratios as the corresponding motors for that charge size. In addition, some of the gross internal features of the propellant grains were also modeled.

Also included in the firing program were replicates of the explosive boosters themselves. These boosters were conically-ended cylinders. They were fired at distances above the ground corresponding to their locations on the corresponding rocket motors (this eliminates any height-of-burst effects in the measurement of the booster output). The complete firing program is outlined in Table 1.

All test items were oriented with their long axis vertical. All were fired over a steel witness plate 3 inches thick. The motors were placed with their nozzles on the bottom--in contact with the witness plate. Similarly, the propellant cartridges were placed with their base plates downward.

The boosters were then emplaced on the top of each test item. If the propellant grain could not be directly exposed to the booster, the interstices between and around the booster and the grain were filled with Composition C-4.

The stated purpose of the tests was to determine the maximum TNT equivalency of these propellants. Concommitant with this is the question, "Did the material detonate, deflagrate, or simply rapidly react?" The TNT equivalency is determined by the measurement of airblast. The violence of the reaction was determined in three ways: (1) high-speed photographs of the event, (2) detonation velocity mesurements along the length of the case, and (3) by the type of dent left in the witness plate.

GENERAL OBSERVATIONS

There was no doubt that the TNT standard charges detonated high order. The damage to the witness plate for each charge ranged from denting the plate to punching a hole, and finally rupturing the plate, depending upon the charge size.

Neither of the gun propellant types (M26 and NACO) appeared to detonate. The witness plates were not dented after. Large pieces of the cartridge cases remained relatively intact (the sides peeled back like a banana). Significant quantities of unreacted propellant were scattered over the test area. (No measurements were made on the quantity of unreacted propellant. However, estimates by observers on site were approximately 10 to 20 percent.)

The SPARROW motors did not appear to detonate. The witness plates were not dented. Large pieces of case material were thrown from ground zero. High speed photographs showed burning propellant being thrown from the ground zero area. Small quantities of unreacted propellant were also located after each shot.

Table 1 Firing Program

Phase	Charge Type	Number of Shots	Nominal Explosive/ Propellant Weight (lb)	Nominal Booster Weight (lb)	Nominal Case Weight (lb)
I	Small TNT standard	3	48.0	5.2	4.0
I	Medium TNT standard	3	145.0	12.5	10.0
I	Large TNT standard	3	351.0	59.0	17.0
I	Small booster	1	-	5.2	-
I	Medium booster	1	-	14.1	-
I	Large booster	1	-	59.2	-
I	MK 58	3	133.0	16.6	78.0
I	MK 37	3	233.0	41.6	140.0
I	MK 30	1	362.0	63.0	181.0
I	5"/54 prop (M26)	3	21.1	5.2	8.5
I	5"/54 prop (NACO)	3	20.6	5.2	8.5
II	Small TNT standard	2	48.0	6.6	4.0
II	B1 (small booster)	2	-	2.0	-
II	B2 (medium booster)	2	-	6.6	-
II	B3 (large booster)	2	-	34.5	-
II	MK 10	2	24.0	6.6	36.0
II	MK 16	2	33.5	6.6	29.0
II	MK 40	3	5.9	2.0	5.5
II	MK 27	1	558.0	35.0	206.0

The ASROC motors appeared to achieve a high order detonation. The witness plates bore the imprint of the nozzle/venturi area of the motor. The motor case material was fragmented into many small fragments--reminiscent of general purpose bomb fragments.

The STANDARD and TARTAR motors did not appear to achieve a high order detonation. Because of the configuration of the motor (a blast tube extending below the propellant grain), even if a high order detonation had been achieved, no plate dent was expected. However, large portions of the case and base material were recovered intact. Large pieces of propellant grain were recovered after the TARTAR firing.

The MK 10 and MK 40 appeared to detonate high order. The MK 16 threw broken pieces of propellant grain over the entire test area.

DETONATION VELOCITY

Detonation velocity was measured in two ways-electronically, using crush switches placed along the outside of the case, and photographically--utilizing high speed cameras operating at 25,000 to 40,000 pictures per second.

Only two items appeared to achieve a true high order detonation--the TNT shots and the ASROC motors. The average detonation rates measured were in excellent agreement with those reported in the literature: For TNT, an average value of 22,600 ft/s (6890 m/s) compared with a value of 22,400 ft/s (6830 m/s);[2] for ASROC motors, a value of 23,700 ft/s (7220 m/s), compared with a value of 23,000 ft/s (7010 m/s) for N-5 propellant.[3] Because of the booster size involved, the ASROC values may be high because the wave was initially overdriven.

The detonation velocity system was behaving erratically during the MK 40 tests; thus no detonation velocity information was obtained. In all of the other cases, the detonation wave apeared to die out--either the pins were not crushed at all, or the slope of the detonation wave position-time indicates the wave was decelerating.

AIRBLAST

The airblast recorded on the program included peak presure, positive duration and impulse, as well as shockwave time of arrival. Least squares curves of the form

$$\ln(f) = A + B\,[\ln(R)] + C\,[\ln(R)]^2$$

were fitted to pressure-distance and impulse-distance data. Here f represents either peak pressure in psi or positive impulse in psi-ms, ln represents the

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[2] Engineering Design Handbook: Explosive Series--Properties of Explosives of Military Interest, Army Materials Command AMC Pamphlet No. 706-177, 29 Jan 1971.

[3] Levmone, S. and Swatosh, J. J., Jr., Blast Parameters and Other Characteristics of N5 Propellant, IIT Research Institute Technical Report ARLCD-TR-77023, Dec 1977.

natural logarithum, R is the range in feet from the charge to the measurement location, and A, B, C are fitting constants.

Figures 1 and 2 present the fitted pressure-distance and impulse-distance curves.

EQUIVALENT WEIGHT CONCEPTS

The equivalent weight of a particular explosive is the weight of some assumed standard explosive (like TNT) required to produce a selected shockwave parameter of equal magnitude to that produced by a unit weight of the test explosive in question. A given explosive will have several equivalent weights, depending on the shockwave parameter selected; i.e., it will have an equivalent weight based on peak overpressure, positive impulse, time of arrival, positive duration, etc. The equivalent weight, based on any given blast parameter, varies, also, as a function of distance from the charge; i.e., the pressure-distance or impulse-distance curve for explosive X is not necessarily parallel to that of the standard. For many purposes, it is sufficient to cite a single equivalent weight number--the average of equivalent weights over some range of pressure.

The basic tenets of similitude imply that comparisons be made between charges of the same shape, confinement, and geometry of interest. The results of such a comparison represent a true measure of the explosive performance.

This is not to imply that comparisons against non-similar are wrong--merely that the results must be interpreted more carefully. For hazard classification purposes, it must be remembered, the DOD classification procedures[4] state that the standard of comparison to be used is a TNT hemisphere.

YIELD CONCEPTS

Utilizing techniques developed and defined in the analysis of nuclear blast yields, an absolute yield (in megacalories) can be determined for any pressure-distance curve. These concepts have been refined and incorporated into the Unified Theory of Explosions (UTE) by F. Porzel.[5] The technique was developed for spherical or hemispherical detonations, but can be applied to cylindrical data as well.

Two "test cases" are described to demonstrate the method: (1) KING nuclear fireball data and (2) the Air Force Weapons Laboratory 1 KT Nuclear Blast Standard.

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[4] Department of Defense Explosive Hazard Classification Procedures, DOD Publication TB700-2 (NAVSEAINST 8020.3, TO 11A-1-47, DLAR 8020.1), Mar 1981.

[5] Porzel, F. B., Introduction to a Unified Theory of Explosions (UTE), NOL TR 72-209, Sep 1972.

The KING fireball data are among the best pressure-distance data in existence: a high yield, air dropped, all fission weapon with negligible mass effect resulting in a perfectly spherical fireball. It spans a pressure range of 4,600 to 190,000 kPa. radio chemistry gave a yield of 545 KT.[6] The UTE yield methodology gave 586 KT. The differences are within the round-off errors in tabulating the original data, let alone possible experimental uncertainty.[6]

The AFWL 1 KT Nuclear Blast Standard is not data but a HULL hydrocode calculation covering the pressure of 7 to 10^6 kPa. The UTE yield derived from the pressure-distance curve is 0.997 KT±14.6 percent--again good agreement.[6]

EQUIVALENT WEIGHT/YIELD ANALYSES

All of the data presented in Figures 1 and 2 were corrected for the effects of the boosters; i.e., the effects of the boosters were subtracted out of the pressure-distance and impulse-distance data. Using these booster-corrected data, equivalent weights based on both peak pressure and positive-impulse were computed as well as a UTE yield for each case. Figure 3 presents an example of the equivalent weight data determined for some of the Phase I results. All of the methods yield essentially the same results. These are summarized in Table 2.

Table 2 Average Equivalent Weight Summary*

TYPE	MATERIAL	TNT EQUIVALENCE (%)
Gun - Single Base	NACO	5[1]
Gun - Double Base	M26	18[1]
Rocket - Composite	MK 58 (SPARROW)	5
	MK 27 (TARTAR)	2
	MK 30 (STANDARD)	36
Rocket-Double Base	MK 37 (ASROC)	75
	MK 16	16
	MK 10	52
	MK 40	71

*[1]5" propellant cartridge

[6]Porzel, F. B., Yield and Blast Analyses with a Unified Theory of Explosions, presented at the 20th Department of Defense Explosive Safety Board Seminar, Norfolk, Virginia, Aug 1982.

Other researchers[7,8] have also investigated NACO and M26 propellants--not in propellant cartridges but in shipping containers. For NACO, they found equivalencies up to 14 percent for 15" diameter or larger shipping containers. For M26, they found a 125 percent equivalency for 15" diameter containers and larger--an obvious charge size effect.

SUMMARY

Propellants, by definition, are energetic materials. Thus, it should come as no surprise that many propellants exhibit significant TNT equivalencies. Even though most do not achieve a high order detonation, they react fast enough to contribute to the airblast produced. It must be remembered that this program was designed to determine the worst case results.

Generally, single base and composite propellants do not appear to detonate (depending upon their critical diameters); double base and high energy propellants do detonate. A major factor keeping the M26 propellant from detonating in the propellant cartridges is the diameter--5 to 6 inches. Anything much larger would probably detonate.

The SPARROW and TARTAR results are consistent with those reported in the literature--but depending on the size of the motor, equivalencies of 40 to 50 percent can be obtained.

Based on the data obtained on this program, material available in the literature, and discussions with NAVSEA Safety, the following (Table 3) suggested revision to OP-5 was presented to the DDESB in August 1983.

Table 3 Suggested Revision to OP-5

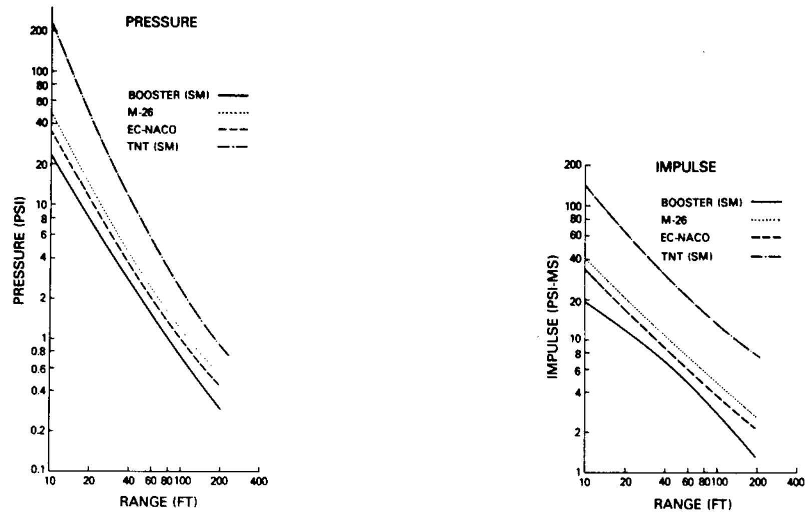
Gun Propellants (5" diameter or less)	0%*
Gun Propellants (>5" diameter)	100%
Composite Rocket Propellants	50%
Double Base Rocket Propellants	100%
Composite/Double Base Rocket Propellants	100%
High Energy Propellants	125%

Use the above values unless a maximum TNT equivalence for the particular motor/materials combination has been experimentally determined.

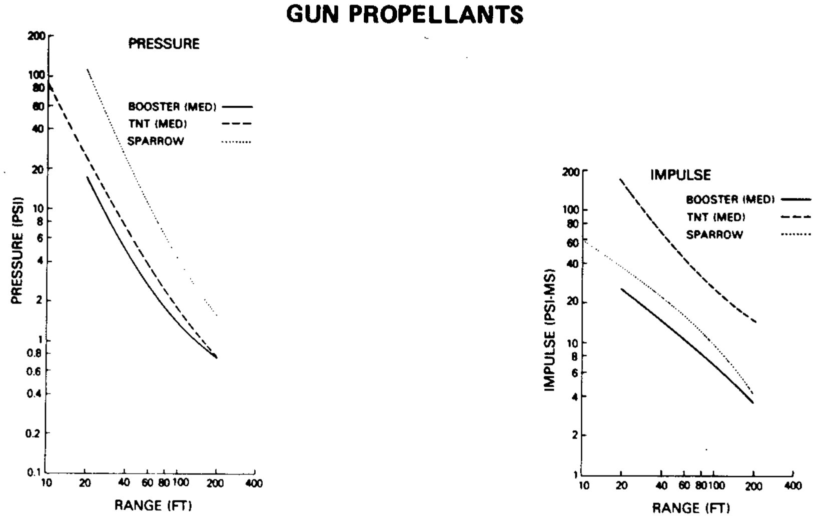
*5-inch diameter charges are below the critical diameter for most charges; moreover it is extremely unlikely that a sufficient stimulus can be brought to bear on these rounds, as they are generally stored separately from their projectiles.

[7] Swatosh, J. J., Jr. and Cook, J. R., Blast Parameters of M26E1 Propellant, IIT Research Institute Report TR 4901, Dec 1976.

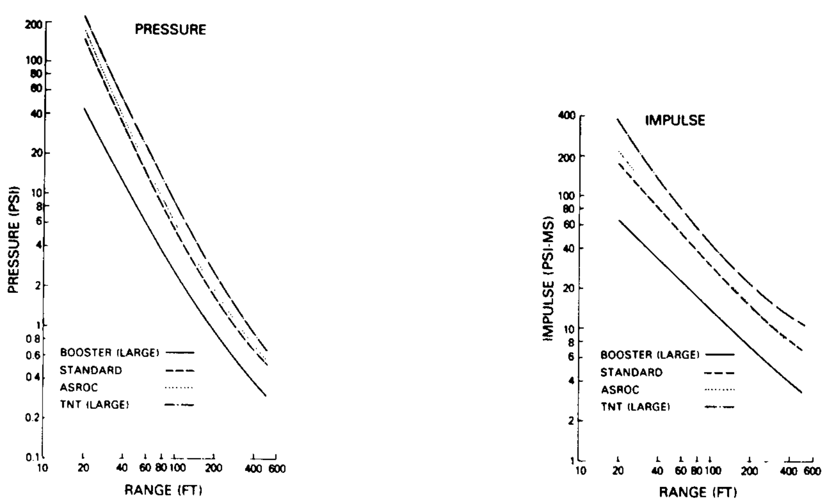
[8] Swatosh, J. J., Jr. and Cook, J. R., Blast Parameters of BS-NACO Propellant, IIT Research Institute Report ARLCD-CR-77003, Apr 1977.



GUN PROPELLANTS

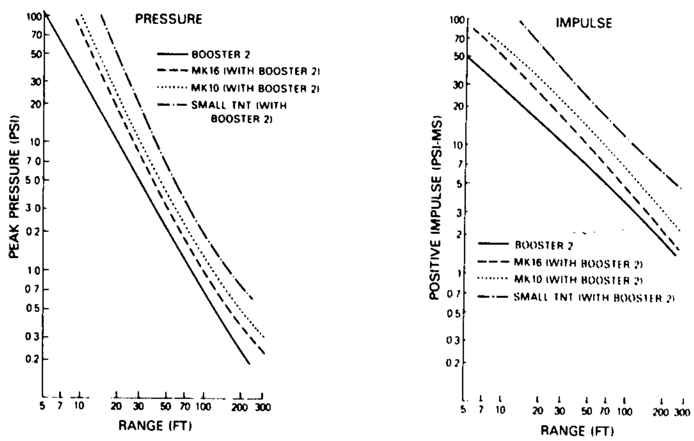


SPARROW

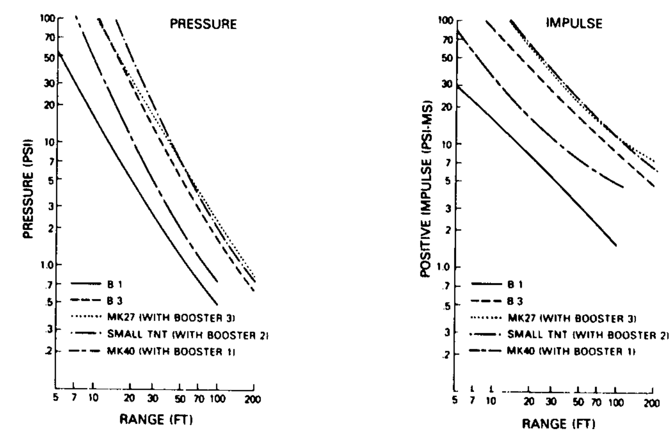


ASROC AND STANDARD

FIGURE 1 PHASE I AIRBLAST COMPARISONS



MK 16 AND MK 40



MK 40 AND MK 27

FIGURE 2 PHASE II AIRBLAST COMPARISONS

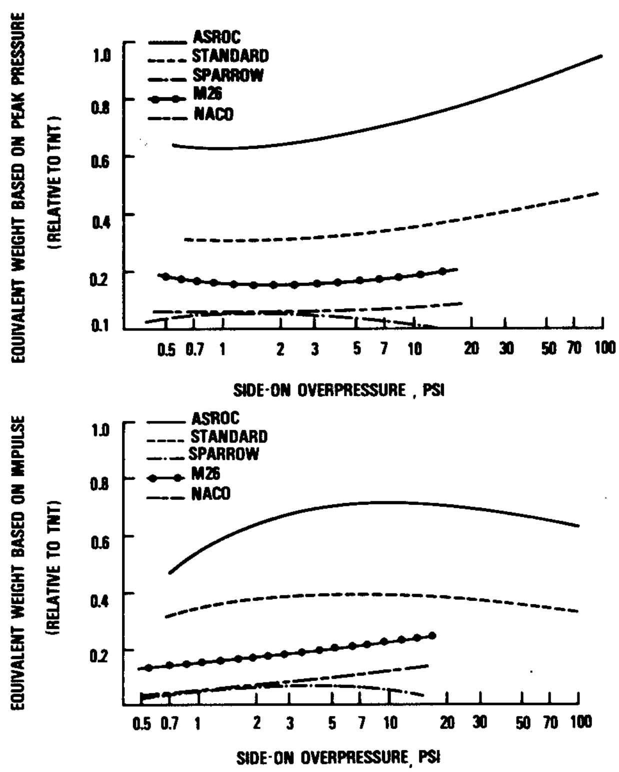


FIGURE 3 PHASE I EQUIVALENT WEIGHT VS. PRESSURE

THE BENEFITS OF STANDARDIZING DESIGNS OF AMMUNITION FACILITIES

Presented By

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Today I will discuss the benefits of standardizing ammunition facilities design and our experience at the US Army Defense Ammunition Center and School (USADACS) in an actual ammunition facility design standardization effort.

The benefits of standard design include a more efficient and effective design through a coordinated users/designer effort, reduced design costs and time, a higher degree of reliability of design and construction costs, reduced construction costs, reduced site submittal documentation and improved compatibility with equipment/processing systems. I will now discuss each of these benefits in detail and present examples from our recently concluded efforts to standardize the design for an ammunition surveillance facility.

Before discussing benefits though, I would like to briefly explain how we at USADACS became involved in standard design of ammunition facilities. USADACS is assigned responsibility for modernization of ammunition facilities under DARCOM-R 740-8, Depot Storage Modernization Program. Additionally, USADACS is assigned responsibilities for providing technical assistance in ammunition logistics, including facilities by AR 700-13, Worldwide Ammunition Logistics Support and Review Program. Involvement of USADACS in the most recent standardization effort, the Standard Ammunition Surveillance Facility, began with a request by USAREUR for information on the security and safety requirements for walls in an ammunition surveillance facility. Recognizing that similar facilities were planned within CONUS at several AMCCOM installations, USADACS contacted the Quality Assurance Directorate, HQ, DARCOM, who in turn tasked USADACS to pursue standardization. USADACS initiated the standardization process by hosting a meeting with representatives of user installations, DARCOM Installations and Services Activity (the design approval agency for DARCOM), DARCOM Field Safety Activity, and USAREUR.

An obvious, and in many aspects the greatest benefit of standardization, is the more efficient and effective design that is obtained through a coordinated users/design effort. The involvement of the users, supporting agencies and review/approval agencies in a direct "face-to-face" encounter results in a better definition of the functions and work to be performed and enhances the understanding of people at all levels in the needs and requirements for the facility.

At the initial Ammunition Surveillance Facility meeting, the functional description or the work to be performed in the facilities was identified and agreed to between participants. As a result of this meeting, much of the work

previously identified to be performed in this facility in individual installation Project Development Brochure - Part I submissions was deleted or changed and other operations not covered were added. This effort greatly enhanced later design efforts. Subsequent to this meeting, USADACS tasked Huntsville Division, Corp of Engineers, to incorporate the results of this meeting and to convert them into a Standardized Project Development Brochure - Part I. This document contains the functional descriptions of work to be performed in the facility and constitutes the basis for design. The attendance of the various review agencies at the initial meeting and at subsequent meetings greatly aided the resolution of questions; for example, a question arose at the first meeting on, "Should the administrative support area of the ammunition surveillance facility be provided Category I or Category III protective construction?" As a result of the meeting, DARCOM Field Safety Activity queried the DDESB and received appropriate guidance. Based on the guidance provided and Huntsville Division's estimate of the added cost of Category I vs Category III protection, the decision was made to proceed with Category I protection for the administrative support area. This early rendering of guidance on this particular point eliminated the potential requirement for a significant amount of redesign later on. Similarly, the participation of DARCOM Security Support Activity resulted in early rendering of guidance on securing the facilities. These early recommendations to concentrate security on the storage cubicles rather than the entire facility reduced security costs and precluded subsequent redesign. These are just two examples of where the "face-to-face" interaction of users/designers and review agencies greatly enhanced the final product.

I would like to digress at this point and discuss an incident where a standard design was implemented, but the results were less than optimum due to the failure to establish a user/developer/design interface. Standardized ammunition facilities are not new. Storage facilities have been standardized for years and have been well received by the user community. Operating facilities, though, have received a mixed reaction, primarily because of a failure to include the ultimate user in the entire development process. A most vivid example is the standard ammunition maintenance facility of which five were constructed in the late 60's. The installation/user had minimum involvement in the development process. As a result, each of the five facilities were ultimately modified by the installations, resulting in five totally different facilities, alike only by the same exterior dimensions. This illustrates the fact that any standardization effort is only as good as the needs of the user are defined and that an optimum facility requires close coordination between the user and the developer/designer. Standardized facilities give an increased opportunity to obtain this type interaction between the various elements. Constraints on travel and time preclude many elements from participating actively in single projects due to the relatively low impact to the entire logistics system from a single facility; however, there is more incentive to participate in a standard design effort since there is a greater potential that a number of facilities will result and that the multiplication effect will result in a greater impact on the system. For example, installing an unnecessary security device on personnel doors may be insignificant for a single facility; but, if ten facilities were built, the amount could become signficant.

A second and obvious result of standardization is a reduction in design costs. Huntsville Division, Corp of Engineers, the designer of the Standard Ammunition Surveillance Facility, estimates that although the initial design of a standard facility is 7.5% of construction costs versus 5.5% for a regular non-standard design, design of subsequent facilities using the standard design can be accomplished for 3% of construction costs. This results in an estimated savings of 2.5% of construction costs for the design of each standard facility vs design of a single facility. With a standard design, since the basic facility design is already complete, all that is generally required of the architectural and engineering firm or the district engineer is to concentrate on the site specific considerations. In the case of the Standard Ammunition Surveillance Facility, the modular standard design permits the addition or deletion of specific portions of the facility based on the individual installation's workload, i.e., number of inspection bays or storage cubicles can be adjusted or an entire capability such as the large missle item bay can be deleted based on installation requirements. The standard design is predicated on specified construction parameters, such as wind loads or siesmic zone. In the case of the ammunition surveillance facility, Huntsville Division, Corp of Engineers, the designer, prepared a site specific handbook which provides the division engineer guidance on adapting the standard facility to local conditions such as soil type, drainage, siesmic zone, wind load, available utilities, local ventilation/heat requirements, etc. Although the site specific designer may be required to make some changes due to local conditions, the main features of the facility such as the building shell, blast walls, work areas, interior lighting, etc. all are part of the standard design and do not require any major engineering design effort.

The reduced design effort required to adapt the standard facility to a particular installation not only results in reduced design costs but also produces a third benefit of reduced design time since the basic facility design is already completed. In the case of the Standard Ammunition Surveillance Facility, changes required to the standard design have been minimal since design parameters used in the standard design have been consistent with local conditions. The most significant change implemented at any of the four installations currently undergoing final design has been the elevation of the facility to dock level at one location, versus ground level design at the other three locations and for the standard design.

A fourth benefit from standardized design is a greater reliability or confidence in construction cost estimates. Availability of a standard design permits development of a more detailed and accurate cost estimate since design details are known. Additionally, if facilities have already been constructed with the standard design, a historical basis is established of actual construction costs. In the particular case of the Standard Ammunition Surveillance Facility design, Huntsville Division, Corp of Engineers provided a detailed cost estimate at approximately the 35% design completion stage. This revised cost estimate was provided the submitting installations having nearterm MCA projects for this type facility. Using these cost estimates, significant reductions of up to 50% in the amount of dollars identified as required for the standard facility resulted. The more accurate cost estimate provided a benefit to these installation in that the reduced funding requirement resulted in the projects receiving greater interest and support at all levels and contributed to the funding for the site specific design of

these facilities. The availability of more reliable design and construction cost data resulting from use of standard designs provides the installation a better tool for identifying their funding requirements in the Military Construction Program, and improves the possibility of the projects being funded. Likewise, a more reliable cost estimate aids installations by minimizing the submission of estimates which are significantly below the actual construction costs, thereby insuring that the installation programs for adequate funding to accomplish the project.

As a result of all of the above actions, construction costs are reduced due to a more efficient design and a more accurate statement of functions to be performed within the facility. There is an increased incentive to reduce costs due to the multiplication effect on cost savings, i.e., $10,000 savings once is $10,000 savings, but when multiplied for five or ten facilities, it becomes a much more significant amount, thereby providing an inherent incentive in the standard design process to reduce costs.

Another benefit of standardization includes streamlined safety site plan submittal documentation since the standard facility can be referenced rather than having to transmit the bulky drawings and specifications through channels to DDESB.

Another significant benefit is improved compatibility with equipment/processing systems. In the case of the Standard Ammunition Surveillance Facility, coordination was made with the Ammunition Peculiar Equipment developer to assure that adequate utilities, ceiling/door heights, floor load limits were provided for existing and planned equipment. Additionally, conduit and a capped water supply were provided to each workbay to provide for eventual installation of fast reaction detection/deluge system based on local conditions without necessitating drilling through the substantial dividing walls.

In summary, there are significant benefits to be derived both operationally and financially to the government by standization of ammunition facilities and the maintainance of a close interaction between users and designers. The path to standardization though is not necessarily easy. Difficulties begin with the identification of a facility as a candidate for standardization. Many times, similar facilities are very difficult to recognize as they are either being proposed with different construction category codes, titles and nomenclature or in different construction program years. For example, the ammunition surveillance facility was being called by various names, e.g., Surveillance Inspection Facility, Surveillance Workshop. Once the facility is identified for standardization, there still remains difficulties in getting the Military Construction Program to recognize the need for standardization, primarily because of the factors previously mentioned. After identifying and obtaining recognition that a facility is a legitimate candidate for standardization, the standardization effort is further hindered by the fact that most organizations, user, review or support agencies, may not have personnel or travel resources available to participate in the design/review process at an optimum level. However, even though these problems do severally hinder the acquisition of standard designs, the benefits are numerous and the effort well worthwhile. There are numerous candidates for standardization which should be pursued. The US Army Defense Ammunition

Center and School has been tasked to standardize a conventional ammunition maintenance facility and has confirmed with FORSCOM/TRADOC the need for a returns processing facility. As a result of observation during the AR 700-13 review program and of needs identified by installations through the Depot Modernization Program, multiple cubicle storage magazines, secure standard above-ground magazines, secure demolition ground storage facilities and less-than-truckload shipping and receiving facilities are required and would make excellent candidates for standardization. We invite all DOD agencies and activities to become involved; to identify candidate facility projects for standardization and to participate to the maximum extent in the development of such standardized designs.

US Army Corps
of Engineers
Europe Division

THE DESIGN OF AMMUNITION MAINTENANCE FACILITIES IN EUROPE FOR THE UNITED STATES ARMY.

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Roger D. Crowson

U.S. Army Engineer Division,
Europe

Frankfurt, West Germany

ABSTRACT

As part of the modernization program for United States Military facilities in Europe, Ammo Surveillance Workshops and Ammo Maintenance Buildings have been designed for construction in several locations within Germany. The facilities were designed by Kocks Consultants GmbH, Frankfurt, West Germany under contract with the U.S. Army Engineer Division, Europe, with Ernst Basler and Partners, Zurich, Switzerland providing the necessary dynamic calculations and design of protective walls. The work bays are separated by walls designed to prevent the simultaneous propagation of an accidental explosion and the administrative office areas are designed to afford personnel protection, even with the inclusion of windows in exterior walls. The facilities will be used for a variety of test and maintenance functions for U.S. Army conventional ammunition of all types.

INTRODUCTION

The United States Army in Europe (USAREUR) is presently engaged in a modernization program for Army ammunition maintenance facilities in Europe. At the focal point of this modernization are two new facilities. They are:

(1) Ammunition Surveillance Workshop

(2) Missile and Ammunition Maintenance Building

These facilities have been designed by Kocks Consultants GmbH, Frankfurt, West Germany under contract with the United States Army Engineer Division, Europe. Ernst Basler and Partners of Zurich, Switzerland designed the protective blast walls for the two facilities. These facilities will be

used by the Army for a variety of test and maintenance functions for conventional ammunitions of all types.

Currently, these new facitilies are planned for the following locations in Germany:

Location	Facility Planned
Miesau	Maintenance and Surveillance
Koeppern	Maintenance and Surveillance
Vielbrunn	Maintenance Only
Weilerbach	Maintenance Only
Muenster	Surveillance Only
Dahn	Surveillance Only
Twisteden	Maintenance and Surveillance
Kriegsfeld	Surveillance Only
Bertrix (Belgium)	Maintenance and Surveillance

At present, Miesau is the only location in West Germany with ammunition surveillance and maintenance facilities. In addition to current ammunition stockpiles, new types of ammunition are arriving as replacements which require more sophisticated checks. It is now necessary to transport all ammunition to Miesau to perform scheduled or needed ammunition maintenance functions. Obviously, the planned construction of new maintenance and/or surveillance facilities at existing ammunition depots and ammunition supply points will eliminate transportation of ammunition over great distances and the possible retrogradation of ammunition to the United States. This new construction will result not only in greater personnel safety, but will also provide a desirable "lower profile" image for the transportation of ammunition.

The purpose of this report is to explain the functions of both new facilities, with an emphasis on the features that have been incorporated into these new designs to ensure that the intended functions of the

buildings can be carried out in a safe working environment. The facility planned for Miesau has been chosen to illustrate these features for this report.

OVERVIEW OF SAFETY FEATURES

The Ammunition Surveillance Workshop and the Missile and Ammunition Building have two primary systems for insuring safety. They are:

(1) Reinforced concrete blast walls separating work bays and test cubicles.

(2) Ultra-high speed deluge system for fire protection.

The laced reinforced concrete blast walls were designed by Basler and Partners. The requirements of these walls are as follows:

(1) Protection of personnel in adjacent work bays in the event of a detonation.

(2) No "sympathetic" detonations. That is, a detonation in one work bay will not result in detonations in adjacent bays.

(3) Protection of personnel in office annexes.

(4) The building must not completely collapse in the event of a detonation. Salvage work must still be possible.

Figure (1) illustrates a typical blast wall. Horizontal and vertical reinforcing steel is provided to resist bending stresses; lacing reinforcement is provided to resist shear. This particular wall is 61 centimeters thick and separates the work bay area of the Ammunition Surveillance Workshop from its adjoining office annex.

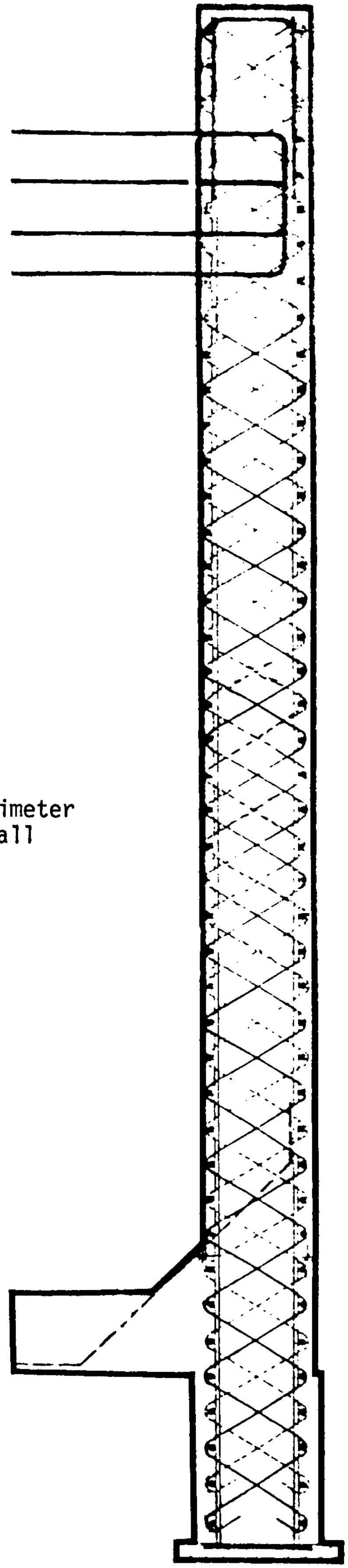


Figure 1- 61 centimeter
blast wall

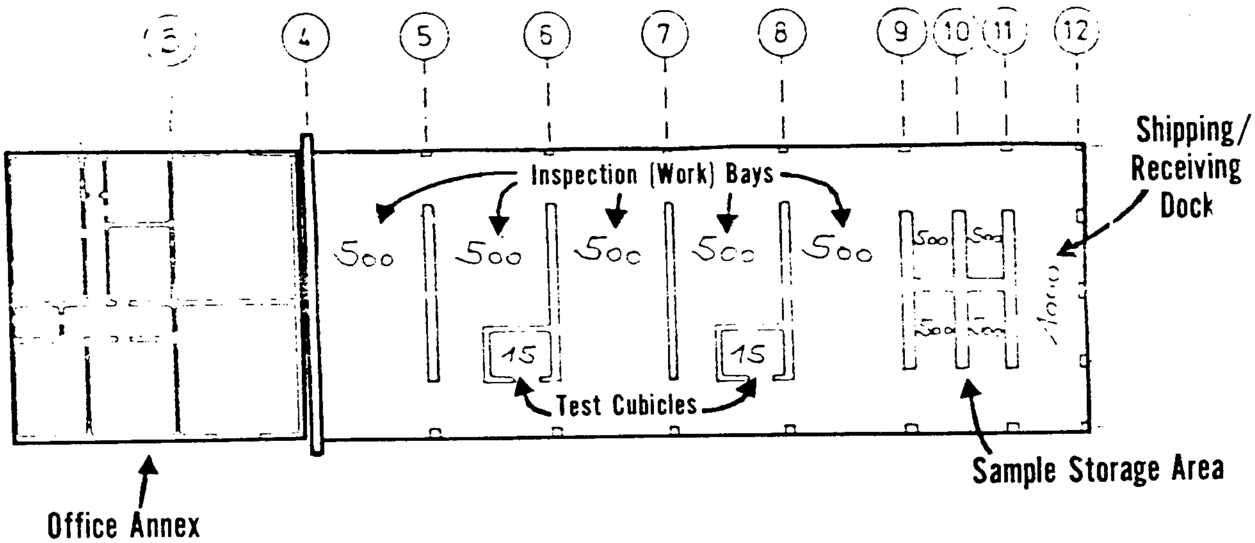
An ultra-high speed deluge system is incorporated into the mechanical design of both facilities to provide protection against fire. This system utilizes an ultraviolet sensor sensitive to wavelengths of light produced by flame. In the event of a fire, these sensors activate the deluge systems, which is statically filled at all times. The deluge system is activated only in the area where a fire is detected. The system will deliver a minimum water application of 20 liters per minute per square meter to the entire area protected by the system. The deluge system will operate within a time interval of approximately 200 milliseconds measured from detection of flame to water discharge. The installation of this deluge system in these planned ammunition facilities marks the first installation in Europe of a deluge system of this type.

AMMUNITION SURVEILLANCE WORKSHOP

The floor plan for the Miseau Ammunitions Surveillance Workshop is shown in Figure (2). The overall plan dimensions of the facility are 246'-6" by 69'-6". Concrete construction is used for the slab-on-grade, for blast walls separating the inspection bays, and for the walls and roof of the test cubicles and office area. Trapezoidal metal deck is used for the roof construction as well as for the exterior walls in the work bay area. In the event of a detonation in the work bay area, this trapezoidal deck will be blown off to vent the explosion and minimize amplification of shock pressures. This floor plan is derived from a standard design developed by the Huntsville Division of the Army Corps of Engineers.

This modern design will provide rooms, bays and areas to accomodate examination of conventional munitions, missiles and ammunition materials

QUANTITIES OF EXPLOSIVE DEPOSIT (LBS.)



AMMUNITION SURVEILLANCE WORKSHOP

FLOOR PLAN

Figure 2

during current and future quality assurance operations. Quality assurance duties will include destructive and nondestructive tests, visual, auditory, olfactory and tactile inspections, and any other physical manipulations, gauging, measurements, components testing, physical and electronic analyses necessary to the systematic collection, analysis and evaluation of facts bearing upon product quality.

The actual inspection processes take place in the work bays. All bays are intended for multi-purpose utilization and are open at both sides to allow maximum flexibility in assembling work stations. Test cubicles are provided with 40 centimeter thick protective blast walls and roof, and will allow the performance of separate individual tests. The sample holding area, with 80 centimeter thick blast walls, is located in close proximity to the work bays and is intended for overnight storage of inspection samples.

In order to provide explosion protection, 61 centimeter thick blast resistant walls are provided in the work bay area, and are designed to resist the charge weights shown on Figure (2). The purpose of these walls is to reduce the catastrophic effects of an explosion so that a detonation in one work bay will not cause a detonation in an adjacent work bay. Although blast pressure and structural motions can produce explosive propagation, the main source of communication of explosions is by primary fragments from the breakup of the donor casing, fragments produced by the fracture of a portion of the structure, or disengagement of interior equipment (Reference 1, TM5-1300, para 3-9d). Therefore, the blast walls are designed to provide the following levels of protection as defined by Reference 1:

Protection category 1 - Personnel must be protected against fragments, blast pressures, and excessive structural motions. A design in this category must prevent the penetration of primary fragments formed by the donor explosive. Wall support rotations must be equal to, or less than, 5 degrees.

Protection category 3 - Prevent communication of detonation by fragments and high blast pressures.

The walls of the test cubicles are designed for protection category 1, as is the wall separating the office area from the work bay area. All other blast walls in the work bay area are designed for category 3.

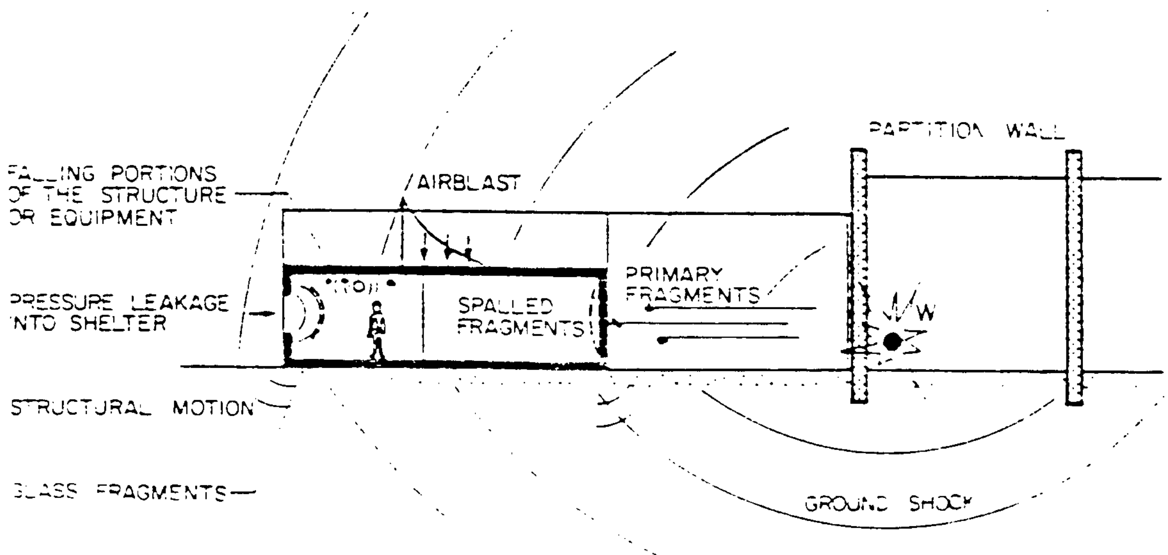
Blast walls along axes 4, 5, 6, 7, 8, 9 and 11 extend 1 meter above roof level. This provides the following additional safety features:

(1) Separation of roof construction by explosion bays.

(2) In the event of a detonation, fragments from the affected bay will not enter into neighboring bays.

(3) Overlapping of fire into a neighboring bay is prevented.

The office annex is separated from the work bay area by a 29 centimeter airspace. This airspace provides additional explosion protection by attenuating structural motions caused by an explosion in the work bay area. Protection category 1 is required for the entire office annex. Figure (3) illustrates the various effects of an explosion and their influences on the office annex. In order to protect personnel against airblast, the roof, outer walls, and the slab-on-grade are designed to withstand the resulting pressure loadings in the event of a detonation. The pressure leakage through the windows are shown to be within acceptable limits. Protection against primary fragments is achieved by providing the blast wall in axis 4 of the building. Direct spalling, scabbing, and



Explosion effects on structure

Figure 3

falling portions of the structure are avoided by limiting the deflections of the outer walls and roof. Falling equipment can be caused by the motion of the entire structure or only a part of it. This motion is caused by the combined effects of airblast, ground shock and direct shock waves in the structural elements. Protection against these effects is provided by separating the office annex from the work bay area and by securely fastening equipment to interior walls and the slab-on-grade.

According to Reference 1, for quantities of explosived up to 25,000 pounds, ground shock effects will usually be small and can be disregarded. The maximum quantity of explosives in the facility is 2,000 pounds; therefore, no special measures were taken against ground shock.

Protection category 1 usually requires that fully enclosed structures be provided. Basler calculated the blast loads onto the wall of the office annex containing the windows and found them to be low. Also, Basler provided a technical paper (Reference 2) which showed analytically that the chance of serious injury due to fragmented glass striking personnel within the office annex is minimal. The maximum energy of the glass fragments was calculated and compared with the energy of the "hazardous fragments" defined in the "NATO Safety Principles for the Storage of Ammunition and Explosives" (Reference 4). Additionally, the window glass to be provided is of a special type (Securit or Temperit) which, upon breaking, fragments into blunt particles which are not as likely to penetrate skin as compared to irregular, jagged glass particles. The fragments of this special glass are also much smaller than fragmented regular glass.

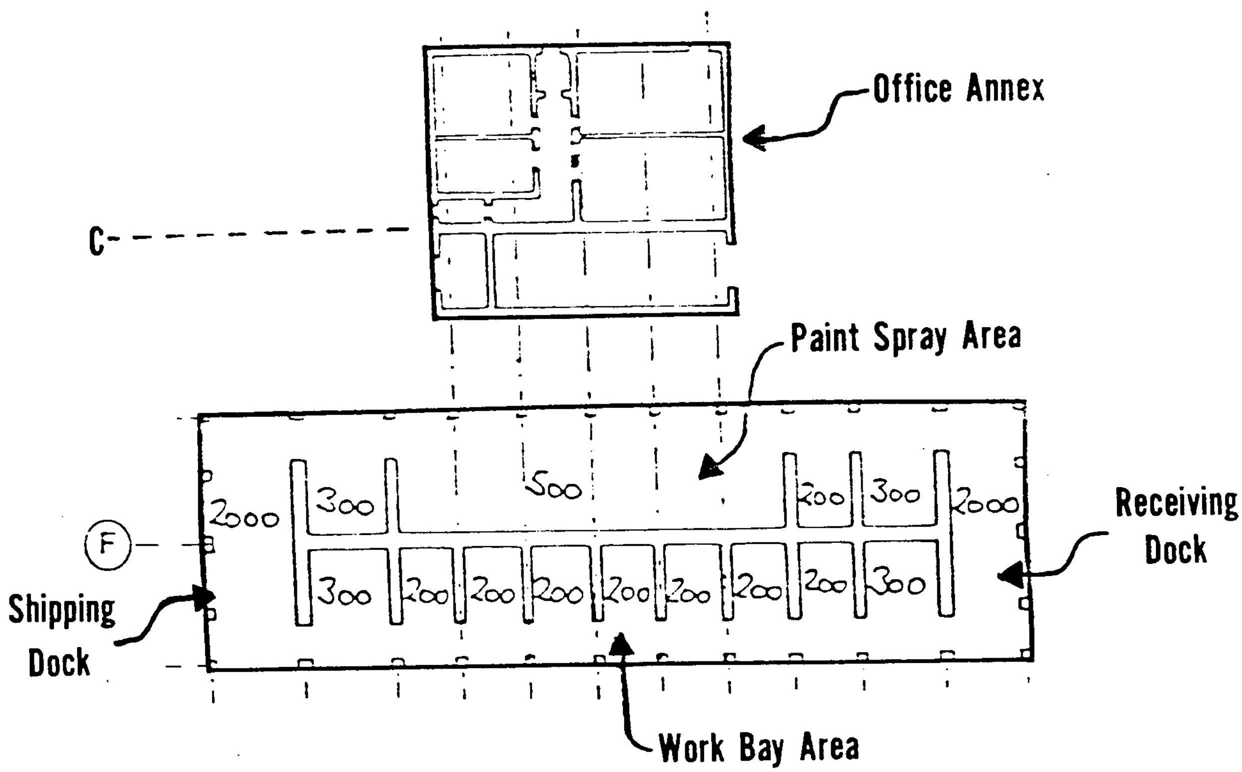
For fire protection, the work bay area of the Ammunition Surveillance Workshop utilizes the aforementioned ultra-high-speed deluge system. One hour fire walls are provided at axes 4, 6 and 8. One hour sliding fire doors are provided for the walls at axes 6 and 8, one at each side of the building. Fifteen emergency exit doors are provided, with the longest runway distance being 12 meters (39 feet). In the office annex, a one-hour fire wall is provided at axis 3.

MISSILE AND AMMUNITION MAINTENANCE BUILDING

The floor plan of the Miseau Missile and Ammunition Maintenance Building is shown in Figure (4). The office annex is separated from the main work area for functional and safety reasons. The overall plan dimensions of the Maintenance building are 169'-9" by 54'-7" with the office plan layout being 59'-8" by 59'-8". As with the Surveillance building, concrete construction is used for slabs-on-grade, blast walls, and for the walls and roof of the office building. Trapezoidal metal deck is used as frangible roof and wall construction in the Maintenance building and as a facade and roof covering in the office annex.

In this facility, unserviceable ammunition will be made serviceable. Maintenance schedules determine workloads for the facility. Periodic checks of ammunition are carried out; these checks are used to determine ammunition maintenance needs. Also, if an item malfunctions in the field (such as a round misfiring) the lot of ammunition from which the defective item originated is designated for maintenance and is scheduled to be transported to the Maintenance facility. Too, if ammunition has been in

QUANTITIES OF EXPLOSIVE DEPOSIT (LBS.)



MISSILE AND AMMO MAINTENANCE BUILDING

FLOOR PLAN

Figure 4

the hands of troops for an extended period of time, it may need repacking. This can be carried out in the Maintenance facility.

This facility is a multi-work bay standard design developed in Europe. The number of work bays required for a particular job is determined by what is known as a Standing Operating Procedure (SOP). The SOP describes the maintenance operations required for a particular type of ammunition and the number of work bays required. All of the bays in the Maintenance building may not be required for a particular job. A SOP for a 155MM HE projectile (howitzer shell) is shown in Figure (5). These SOP's are developed at the ammo depot by the use of a Depot Maintenance Work Requirement (DMWR). The DMWR states the technical requirements for a particular job. Every ammunition item has a different DMWR which affects the number of work bays required. Typical maintenance operations are derusting, preservation/packing, ultrasonic testing, eddy current testing, corrosion control, defusing, re-fusing, re-priming, de-priming, stencilling and painting.

The explosion protection measures for the Maintenance building are analogous to those of the Surveillance building. Blast resistant walls are used between the individual work bays. The frangible metal deck roof and exterior walls provide vent openings in case of a detonation. In this design, the wall in axis "F" extends above roof level to separate the paint spray area from the work bays. This wall is 70 centimeters thick. The blast walls between the individual work bays are 60 centimeters, while the walls at the shipping and receiving docks are each 105 centimeters thick. This wall is shown in Figure (6). All blast walls are designed to resist the blast pressures due to the individual charge weights shown on Figure (4). No extra measures are needed for primary fragment perforation,

SOP NO: RHN-M-284 DATE: 23 November 1982

REV NO: 2 DATE: 2 March 1984

CHANGE NO: ______ DATE: ______

OPERATIONAL INDEX

OPER NO	BLDG NO OR SITE	BAY NO	TOTAL EXPLOSIVE ALLOWED IN BAY	LBS	DESCRIPTION OF OPERATION
1	1552(D)	1	384 Projectiles	2,400.00	INCOMING STORAGE, INSPECTION AND CLEANING OF PROJECTILES
2	-"-	2	NONE	NONE	START-UP PROCEDURE FOR ULTRA SONIC AND EDDY CURRENT TESTING
3	-"-	2	120 Projectiles	750.00	ULTRASONIC AND EDDY CURRENT TESTING
4	-"-	2A	8 Projectiles	50.00	CLEANING AND TOUCH-UP OF PROJECTILES, APPLICATION OF LOT SUFFIX
	-"-	4	4 Projectiles	25.00	
		5	4 Projectiles	25.00	
		6	4 Projectiles	25.00	
		7	4 Projectiles	25.00	
		8	352 Projectiles (See Note below)	2,200.00	
5	-"-	8	Included in Operation No 4 (See Note below)		PALLETIZATION OF REJECTED PROJECTILES
6	-"-	8	Included in Operation No 4 (See Note below)		PALLETIZATION OF ACCEPTED PROJECTILES
7	-"-	8	Included in Operation No 4 (See Note below)		GAGE PROJECTILE
8	-"-	8	Included in Operation No 4 (See Note below)		HOLDING AREA FOR TWO HOUR'S PRODUCTION, OGIVE PRIMER COATING, OGIVE FINISH COATING, STRAPPING AND OUTGOING STORAGE
		16	176 Projectiles	1,100.00	
		9	72 Projectiles	450.00	
		15A	72 Projectiles	450.00	
9	-"-	10	72 Projectiles	450.00	HOLDING BAY FOR REJECTS AND STRAPPING
		11	72 Projectiles	450.00	
10	-"-	13,15	Packing Material	NONE	HOLDING BAY FOR PACKING MATERIAL
11	-"-	8	Packing Material	NONE	PAINTING AND MARKING OF PALLETS
12	-"-	9	Included in Operation No 8		SPECIAL REWORK OPERATION FOR PROJECTILES
		11	Included in Operation No 9		

TOTAL EXPLOSIVES: 8,400.00 LB

Figure 5

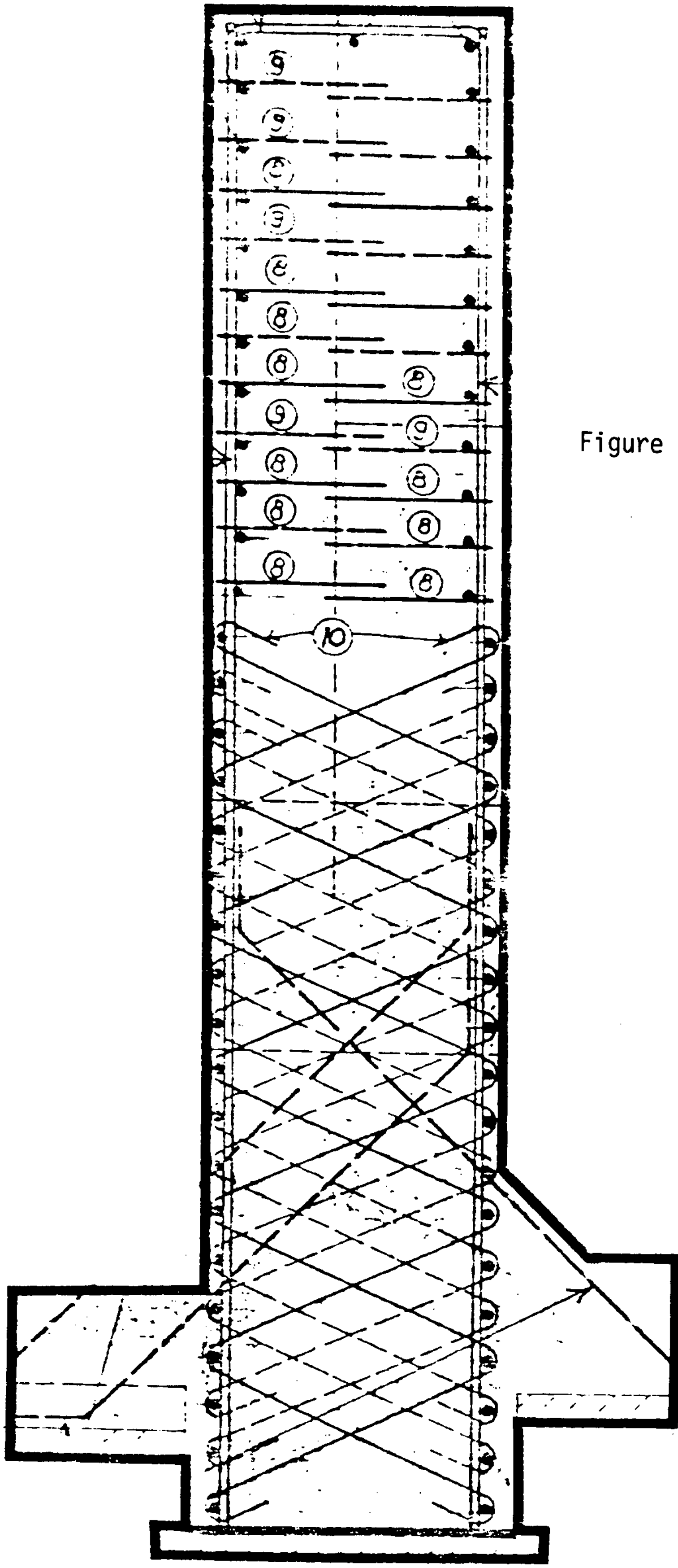


Figure 6- 105 centimeter blast wall

spalling, scabbing or local affects as the wall thicknesses are sufficient. All walls in the Maintenance building are designed for protection category 3.

The office annex is separated from the Maintenance building by a distance of 6 meters and is located on the paint spray area side of the Maintenance building, away from the work bay area with its higher charge weights. Functionally, the office annex cannot be located integrally with the Maintenance building as is done with the Surveillance workshop because of the operational placements of the shipping and receiving docks. The office annex is designed for protection category 1.

For the evaluation of the blast loadings onto the office annex, airblast attenuation from explosions in three different bays were investigated. These were detonations of 2,000 pounds in either the receiving or loading dock and 500 pounds in the paint spray area. The charges in the dock areas were assumed to be surface charges. For the evaluation of a blast loading due to an explosion in the paint spray area, a cubicle model was used. The resulting design protection features are analogous to those for the Surveillance Workshop office annex. The main difference is that, due to its 6 meter separation from the Maintenance building, this office annex does not require a partition wall as does the office annex in the Surveillance building. Protection against primary fragments, direct spalling and scabbing requires no additional measures in either office annex.

For fire protection in the Maintenance building, the aforementioned ultra-high-speed deluge system is provided in the work bay area only. A conventional sprinkler system is utilized at the shipping/receiving docks and in the paint spray area. Seven emergency exit doors are provided on each side of the building. The longest runway to the nearest exit is

9.5 meters (31 feet). The office annex has a one-hour fire wall in axis "C". In both office annexes, fire extinguishers will be user provided.

CONCLUSION

To insure efficient inspection and maintenance of its current and future ammunition stockpiles in Europe, the United States Army has planned construction for new Ammunition Surveillance Workshops and Missile and Ammunition Maintenance Buildings. These facilities will provide optimum functional capabilities as well as incorporate state-of-the art safety features. Work bays are separated by concrete blast walls designed to prevent sympathetic propagation of accidental detonations. Office areas are designed to afford personnel protection, even with the inclusion of windows in exterior walls. An ultra-high-speed deluge system has been incorporated into the mechanical design of both facilities to provide fire protection. When completed, these facilities will be used by the United States Army in Europe for a variety of inspection, test, and maintenance functions for conventional ammunition of all types.

REFERENCES

1. "Sturctures to Resist the Effects of Accidental Explosions", Department of the Army Technical Manual TM5-1300, Washington, D.C., June 1969.

2. "Notes on the Arrangement of Windows in the Office Annexes", Ernst Basler and Partners, Zurich, Switzerland, February 1984.

3. "Technical Report to Structural Design of Office Annexes", Ernst Basler and Partners, Zurich, Switzerland, September 1983.

4. "NATO Safety Principles for the Storage of Ammunition and Explosives", NATO AC258, 1982.

EXPLOSIVE SAFETY CRITERIA AT A DEPARTMENT OF ENERGY CONTRACTOR FACILITY

Fred Krach, P.E.

Mound*

Miamisburg, Ohio

ABSTRACT

Monsanto Research Corporation (MRC) operates the Mound facility in Miamisburg, Ohio, for the Department of Energy. Small explosive components are manufactured at MRC, and stringent explosive safety criteria have been developed for their manufacturing. The goals of these standards are to reduce employee injuries and eliminate fenceline impacts resulting from accidental detonations. This paper will describe the manner in which these criteria were developed and what DOD standards were incorporated into MRC's own design criteria. These design requirements are applicable to all new construction at MRC. An example of the development of the design of a Component Test Facility will be presented to illustrate the application of the criteria.

*Mound is operated by Monsanto Research Corporation for the U.S. Department of Energy under Contract No. DE-AC04-76DP00053.

DEPARTMENT OF ENERGY (DOE) EXPLOSIVES SAFETY STANDARDS

The DOE has developed a "DOE Explosives Safety Manual," DOE/EV/06194-2, that contains explosives facility design criteria. Paragraph 6.4 of that document, titled "Explosive Facility Siting and Design Criteria," is reproduced below.

6.4 Explosives Facility Siting and Design Criteria

In addition to this manual, the following are resource documents for the siting and design of explosives facilities:

- DOE Order 6430 - Department of Energy General Design Criteria Manual, Chapter XXII
- TM 5-1300 - Structures to Resist the Effects of Accidental Explosions
- DOE/TIC-11268 - A Manual for the Prediction of Blast and Fragment Loading of Structures
- DOD 5154.4S - Department of Defense Ammunition and Explosives Safety Standards
- TR-828 - Blast Environment from Fully and Partially Vented Explosions in Cubicles
- AD 411445 - Industrial Engineering Study to Establish Safety Design Criteria for use in Engineering of Explosives Facilities and Operations
- AFWL-TR-74-102 - The Air Force Manual for Design and Analysis of Hardened Structures

- o HNDM-1110-1-2 - Suppressive Shields, Structural Design and Analysis Handbook.

As can be seen, some of the principal DOE design criteria are military references. This makes alot of sense. Why re-invent the wheel? This DOE manual evolved over the past five years and was co-ordinated by DOE Headquarters, Washington, D.C. A Manual Committee, which includes representatives from many DOE internal and contractor facilities, meets twice a year and constantly up-grades the manual. Mound has a representative on that committee.

The Manual Committee intends to form a sub-committee dealing with facility design criteria only. The present manual deals with the entire subject of explosives safety with emphasis on operational safety. The idea of the Design Criteria Sub-Committee would be to exchange information among facility designers and design reviewers, many of whom are at this seminar.

MOUND'S EXPLOSIVES FACILITY DESIGN CRITERIA

MRC operates the Mound site for DOE in Miamisburg, Ohio, a suburb of Dayton, Ohio. Because Mound is situated on a 300-acre site, within the city limits of Miamisburg, we are particularly sensitive to our neighbors' reactions to any planned or accidental detonations. This sensitivity affects our explosive facility fenceline design criteria.

Accordingly, to avoid any "temporary threshold hearing shift" in any person who might be at our fenceline, we site Class I and Class II explosive operations (the more dangerous operations) so that a temporary hearing shift will not result if an accidental detonation should occur. We do not want any detonation pressure pulses to exceed 0.2 psi at our fenceline.

These facilities will be sited according to the equation:

$$D_1 = 100\ W^{1/3}$$

where "D_1" is the distance from the fenceline, in feet, of a Class I or II operation containing "W" (pounds) of explosives. "W" is the TNT equivalent weight of the explosives in the process.

For example, an operating facility processing 10 lb of H.E. would have to be:

$$D_1 = 100\ (10 \times 1.3)^{1/3}$$

1.3 is used to convert our typical H.E. to TNT.

$$D_1 = 100\ (13)^{1/3}$$

$$= 100\ (2.35)$$

$$= 235 \text{ ft from the nearest fenceline.}$$

For Class III operations (low risk storage facilities), we do not want an accidental detonation from a Class III area to cause broken windows at the fenceline.

Because we want to avoid generating 0.5 psi pressure pulses at the fenceline, Class III facilities will be sited in accordance with:

$$D_2 = 60\ W^{1/3}$$

Thus, a magazine containing 1,000 lb of H.E. would need to be:

$$D_2 = 60\ (1000 \times 1.3)^{1/3}$$
$$= 60\ (1300)^{1/3}$$
$$= 60\ (10.91)$$
$$= 655 \text{ ft from the nearest fenceline.}$$

(Fragment distance criteria is considered separately.)

These above examples are typical of applications at Mound. Because most of our development and production deals with small explosive components, 10 lb of H.E. is about the maximum amount of H.E. that we would accumulate in one operation. Also, the newest large magazines at Mound contain less than 2,000 lb of H.E., so the above examples are realistic ones for Mound.

Because most of our components are in gram quantities of H.E., we can afford certain luxuries in our explosives safety criteria. The fenceline criteria above is one example. Other examples are the stringent criteria we impose to protect our personnel. Thus, we use $D_3 = 50\ W^{1/3}$ for our inhabited building criteria, unless the "receivers" have no windows facing the explosives operation.

We also design our walkways so that personnel will not be knocked down if there is a accidental detonation. The logic here is that an explosive worker may be carrying small explosive components in an open tray in explosive exclusion areas. If that worker is knocked down, he may spill explosives, potentially causing them to detonate. This may be similiar to a military 5 psi exclusion area, depending on charge weights (impulse).

For still another example of MRC policy, we don't want our workers to be exposed to noise levels exceeding OSHA guidelines (140-db impulse) for intentional test detonations. Also, we design plastic (Lexan or equal) barricades for as many operations as can be practically barricaded from the worker.

A PROJECT EXAMPLE OF MOUND SAFETY DESIGN CRITERIA

To illustrate some of the many environmental and safety reviews of the design of an explosive facility at Mound, I have selected our new Component Test Facility (CTF) as an example.

The CTF has been designed and, at this writing, is being built to destructively test (detonate) up to 10 lb (TNT equivalent) H.E. in totally containing test cells. This 34,000 square foot facility is shown in Figure 1. The facility contains 3 large steel test cells, 15 ft in diameter and 24 ft long. The shells are 1-3/4 in. thick and lined to absorb the shock of repeated test shots. Each test cell exhausts into an expansion chamber containing more than twice the volume of the test cell. For large shots, the expansion chambers are interconnected and a total expansion volume approximately seven times the test cell volume is available.

Camera rooms surround each test cell, and high-speed cameras photograph test shots through windows in the test cells.

On the explosives processing side of the building are test control rooms and explosive preparation areas. The preparation areas are designed to vent to the rear of the building any accidental detonations during preparation or handling.

ENVIRONMENTAL EVALUATION

All major construction projects at Mound are evaluated for any potential environmental impact. The initial evaluation is called an Action Description Memorandum (ADM), and is submitted to DOE. They may decide a more in-depth study (up to an Environmental Impact Statement) is required. The appropriate environmental documentation is finally prepared, reviewed, and approved by DOE. For the CTF, the ADM, which addressed issues like disposal of waste H.E. and ventilation control, was adequate.

SYSTEM SAFETY STUDY

To ensure that all safety features were well planned for the CTF, Mound's system safety function in a group called Loss Prevention and Environmental Control (LP & EC) recommended and coordinated a Hazard and Operability Study (HAZOP), which is a popular system safety study technique in the chemical industry.

During a HAZOP, each step in a process is reviewed. In the case of the CTF, the test process was studied. This study is documented and the recommendations are incorporated into the design of the facility.

Several design and operating safety recommendations were generated during the CTF HAZOP. However, a very important product of the process is the comfortable feeling, generated by the study process, that many involved personnnel (nine for the CTF) have thoroughly analysed the process. All major safety issues are covered, and all participants become better acquainted with the process. Thus, during future design reviews, the HAZOP participants have a good understanding of the project sponsor's needs.

In the case of the CTF, the HAZOP was performed after the safety review of the Conceptual Design Report and prior to the review of the Design Criteria Document. The design criteria is used by the architect and engineering design company to generate the final design of the facility.

SAFETY ANALYSIS REPORTS (SAR)

An SAR is a formal safety review documenting an in-depth analysis of a major explosive facility (such as the CTF). DOE Order 5481.1A provides a detailed outline of the SAR procedure and processes. The preliminary SAR (PSAR) for the CTF was submitted and generally approved prior to release of funds by the DOE. The final SAR (FSAR) will be authorized by DOE prior to facility start-up. At this writing, that is still several fiscal years away. SAR's contain 19 prescribed chapters of detailed analysis. The analyses range from accident analysis through environmental and waste management programs to a plan for decommissioning the facility.

A major benefit of the PSAR process for our CTF was the decision to make the explosive corridor in the middle of the CTF into a tornado shelter. Since this corridor was already reinforced for explosive processing, adding heavy doors to the ends of the central corridor made an inexpensive tornado shelter.

LOSS PREVENTION AND ENVIRONMENTAL CONTROL (LP & EC)

All of the safety analysis functions described herein are performed under Mound's LP & EC umbrella. The LP & EC Project Administrator reviews any potential project losses and environmental issues.

All major designs are thoroughly reviewed by a team of LP & EC resource personnel at each project milestone. Further, once the processes become operational, they are reviewed periodically (at approximately 3 year intervals), or when major process changes occur. This review process remains active until a process/facility is decommissioned. This we call our "cradle to grave" LP & EC coverage.

As this review process is applied repeatedly, standardized facility design techniques evolve. Explosive safety criteria is generated by the LP & EC during the design/concept review process. This criteria is inserted into the design criteria documents which are approved by Mound's managing directors.

To assist us in explosive facility design, we recently contracted several specialist A&E/consulting firms, under blanket contracts to generate and review designs. These firms may even help write SAR's and some of the other documentation discussed earlier in this presentation.

SUMMARY

Monsanto Research Corporation operates Mound for the Department of Energy in Miamisburg, Ohio. MRC operates, and is building more, explosive process facilities at Mound. Most of the design standards incorporated into new explosive facilities are Department of Defense standards. The principal design standards are listed in the DOE Explosives Safety Manual (DOE/EV/06194-2).

Because Mound produces small explosive components at a relatively small plant site in a densely populated area, explosive design criteria are more stringent than the DOE standard, especially for fenceline, facility explosive clearances, employee knock down, and employee noise exposure criteria.

Monsanto's Loss Prevention and Environmental Control system has been in place for several decades. The system has led Mound to achieve a world's safety record for chemical laboratories (over ten years without a lost work day case).

The ultimate objective of all explosive safety design, and any other loss prevention, environmental control, health, or safety technique and program is the reduction of human suffering. To that end, Monsanto and all DOD Explosive Safety Board meeting attendees remain dedicated. That is why we develop our explosive facility standards, and that is why we attend these meetings. It is hoped that there are some useful criteria here for others, as we all remain ever diligent to advance our profession. It is a growth process, in which I feel privileged to be constantly learning.

APPENDIX

FIGURE 1 - C. T. F.

VUE-GRAPHS USED FOR VERBAL PRESENTATIONS

COMPONENT TEST FACILITY MRC—Mound

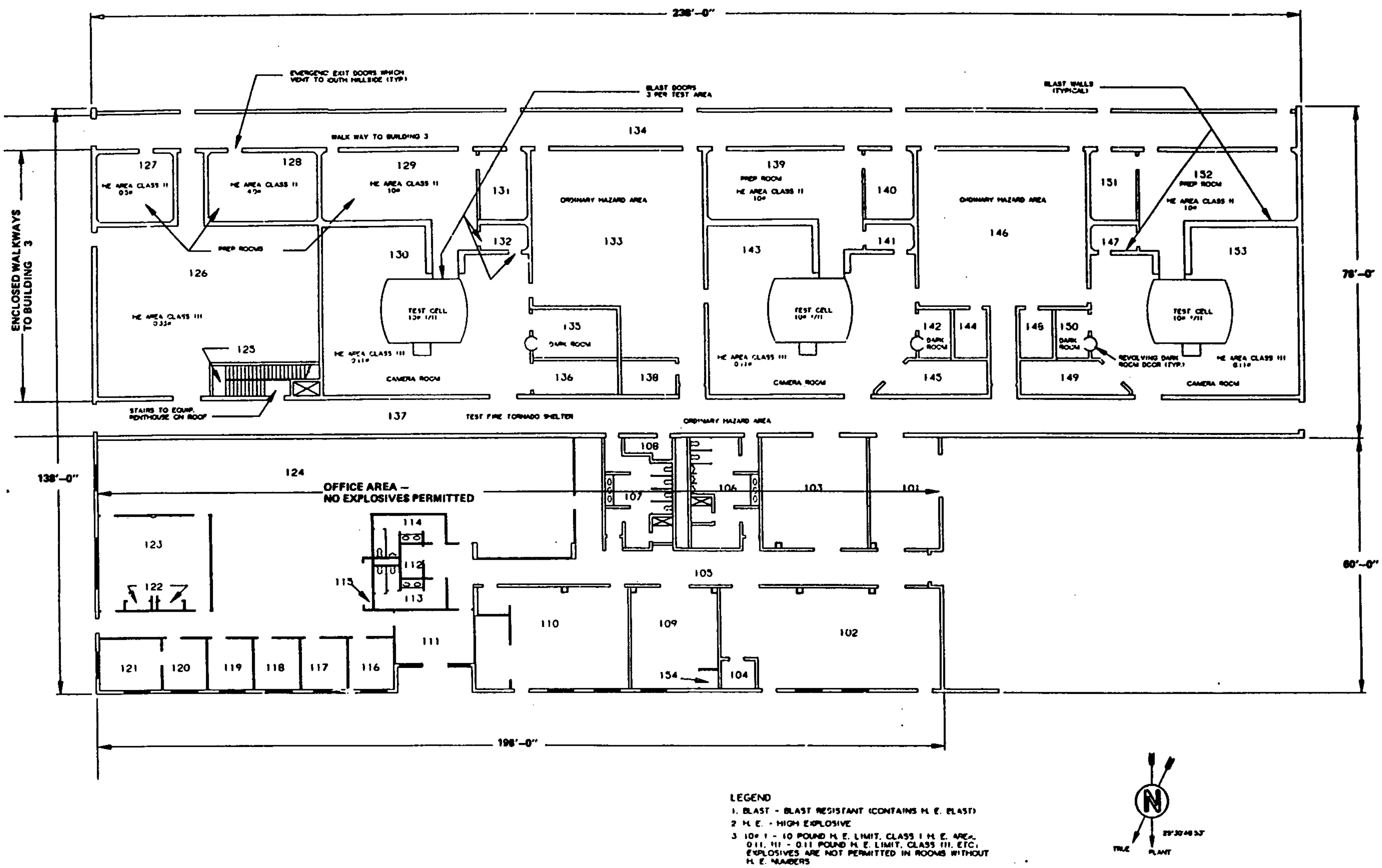


FIGURE 1

EXPLOSIVE SAFETY CRITERIA AT A DEPARTMENT OF ENERGY CONTRACTOR FACILITY

FRED KRACH, P.E.
MONSANTO RESEARCH CORPORATION

AUGUST 30, 1984

FOR
DOD EXPLOSIVE SAFETY BOARD
21ST SEMINAR

MONSANTO RESEARCH CORPORATION (MRC) EXPLOSIVE SAFETY CRITERIA IS SIMILAR TO DOD CRITERIA

- *DOE STANDARDS*
- *MRC IS MORE STRINGENT*
- *PROJECT EXAMPLE*
- *MRC'S LOSS PREVENTION AND ENVIRONMENTAL CONTROL SYSTEM*
- *STANDARDIZED FACILITY DESIGN (DOD/DOE)*

DEPARTMENT OF ENERGY (DOE) EXPLOSIVES STANDARDS

- *DOE EXPLOSIVES SAFETY MANUAL (DOE/EV/06194-2)*
- *DOD STANDARDS INCORPORATED INTO DOE STANDARDS*

DOE EXPLOSIVES SAFETY MANUAL

- *HISTORY*
    - *COMMITTEE*
    - *PROPOSED SUB-COMMITTEE*
- *LIVING DOCUMENT*
  (2 MEETINGS PER YEAR)

MRC IS MORE STRINGENT THAN DOE

- *NEIGHBOR SENSITIVITY*
    - *MRC FENCELINE CRITERIA*
- *SMALL COMPONENTS*
    - *NO KNOCK-DOWN CRITERIA*
    - *NOISE CRITERIA (OSHA)*

MRC FENCELINE CRITERIA

- *CLASS I & II OPERATIONS* $P_S = 0.2$ *MAX*
  - *THRESHOLD OF HEARING SHIFT* $D = 100\ W^{1/3}$
- *CLASS III OPERATIONS* $P_S = 0.5$ *MAX - BREAK WINDOWS* $D = 60\ W^{1/3}$

MRC EXPLOSIVES FACILITY DESIGN DEVELOPMENT

- *COMPONENT TEST FACILITY (CTF)*
  - *ENVIRONMENTAL STUDY (ADM)*
  - *HAZOP*
  - *PSAR/FSAR*
  - *LOSS PREVENTION & ENVIRONMENTAL CONTROL REVIEWS*
- *MAGAZINES*
- *TEST CELLS*
- *DETONATOR STORAGE FACILITY/BUILDING 72*

MONSANTO'S LOSS PREVENTION AND ENVIRONMENTAL CONTROL (LP&EC) SYSTEM

- *MONSANTO HISTORY OF LP&EC*
  - *CHEMICAL INDUSTRY*
- *DESIGN REVIEWS*
  - *EXPLOSIVE FACILITIES*
    - *SUB-CONTRACTORS WITH EXPLOSIVE EXPERTISE*
- *PROCESS REVIEWS*
- *SYSTEM SAFETY (HAZOP, FAULT TREE, ETC.)*

SUMMARIZING KEY SAFETY CRITERIA ISSUES

- *DOE USES MUCH DOD CRITERIA*
- *MRC MORE STRINGENT THAN DOE*
  - *NEIGHBOR SENSITIVITY*
  - *CHEMICAL INDUSTRY*
- *SMALL COMPONENTS*
- *FENCELINE CRITERIA*
- *NOISE CRITERIA*
- *NO KNOCK DOWN CRITERIA*

OBJECTIVE OF EXPLOSIVE SAFETY — REDUCE HUMAN SUFFERING

PREDICTION OF DEBRIS HAZARDS FROM EXPLOSIONS IN BUILDINGS

presented at:

21st Department of Defense
Explosive Safety Seminar

28-30 August 1984

by

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Port Hueneme, California 93043

INTRODUCTION

The Naval Shore Establishment has a large number of explosive-handling facilities, such as weapon assembling facilities, weapon maintenance buildings, and missile test cells, that are subjected to Department of Defense Explosives Safety Board (DDESB) regulations and rules. For facilities with less than 30,000-lb TNT equivalent of net explosive weight, DDESB requires that no inhabited building be within a radius of 1,250 feet from the ordnance facility, unless it can adequately demonstrate by technical data that a lesser distance would result in no more than one fragment or debris missile per 600 ft^2 of ground surface area with an impact energy exceeding 58 ft-lb. To date, no unhardened facility has been sited at less than 1,250 feet without a safety waiver, because no reliable prediction method can demonstrate the "required" safety distance based on the DDESB "58 ft-lb/600 ft^2" criterion.

In view of the potential cost savings, the Naval Civil Engineering Laboratory (NCEL) has been developing a Monte-Carlo probabilistic methodology (Ref 1) for predicting the debris hazard from an explosion in a building by simulating the actual flight trajectories and impact locations of every debris missile resulting from the explosion. The resultant debris missile impact histogram depicts the accumulated number of hazardous debris missiles (impact kinetic energy >58 ft-lb) within 600 ft^2 ground area at various impact ranges. The debris safety distance can then be easily determined from this multiple debris missile impact histogram.

Each Monte-Carlo calculation of the debris missile impact histogram represents one possible outcome of the experimental test under the same test conditions. To obtain confidence in the prediction, one can repeat the Monte-Carlo calculation as many times as needed by using different random number generator "seeds."

Theoretical formulas and experimental data bases for determining debris launch characteristics, both the magnitude and probability density distribution, are still primitive and cursory. However, with more emphasis on the probabilistic approach from the explosives safety technical community, the situation should improve greatly. NCEL, with limited funding and resources, is currently planning some small scale experimental tests to obtain data for debris launch characteristics.

MULTIPLE DEBRIS MISSILE IMPACT SIMULATION

The Multiple Debris Missile Impact Simulation (MUDEMIMP) is a computer program that determines debris hazard by calculating the accumulated number of critical debris missiles at various impact ranges. Critical debris missiles are defined by DDESB as those with terminal kinetic energies greater than or equal to 58 ft-lb.

The MUDEMIMP employs a probabilistic approach in solving the multiple debris hazard problem by utilizing Monte-Carlo sampling techniques to assess the effects of variations and uncertainties on the debris launch characteristics (Ref 1). The debris missile impact simulation starts by selecting one debris missile from the total debris with Monte-Carlo selected debris launch and flight parameters. Then, the computer calculates the trajectory, impact range and terminal kinetic energy of this particular sample debris missile. This Monte-Carlo random sampling process is repeated on the remaining debris missiles until all the debris have been sampled (Ref 2).

Five independent launch characteristics have been identified as the key parameters in determining debris impact range and are used in the Monte-Carlo random sampling process; they are: launch velocity (V), launch elevation angle (θ), debris missile mass (m), drag cross-section area (A), and drag coefficient (C_d). Each debris probability density function represents the variation of frequency of occurrence versus the values of the parameter. It is clear that in order to obtain a realistic simulation on the multiple debris missile impact histogram, a meaningful probability density function must be used to represent the input parameter. The current MUDEMIMP simulation computer program has the capability of randomly sampling the following input probability density functions which should be adequate for most applications:

- o Uniform (straight line)
- o Normal (Gaussian)
- o Exponential
- o Beta
- o Log-normal
- o Weibull

The MUDEMIMP also has the capability to plot the final Monte-Carlo sampling accumulated distributions for the five input parameters so that a direct comparison can be made between the theoretical input functions and the actual Monte-Carlo random sampling results.

Even though the MUDEMIMP computer code was designed based on the DDESB 58 ft-lb criterion for hazardous debris missiles, the program does provide the capability to vary the 58 ft-lb hazardous criterion by inputing a specific value that is required or dictated by the situation. This option allows MUDEMIMP to solve a number of different debris hazard problems, such as debris hazards for buildings rather than human body, block wall penetration, etc.

There are three different execution modes in the MUDEMIMP for solving various debris hazard problems. First is the "Standard Execution" which depicts the debris hazard from one single Monte-Carlo cycle simulation for one structural mesh element. Second is the "Multiple Execution" which determines the combined debris hazard from one single Monte-Carlo cycle simulation for structual mesh elements. Third is the "Repeated Execution" which repeats the Monte-Carlo simulation N cycles (with different "seeds") for one structural mesh element in order to obtain a confidence level. Each repeated execution represents a repeated experimental test under the same explosion conditions.

SAMPLE CASE ILLUSTRATION

To illustrate the application of MUDEMIMP in debris hazard prediction, a Missile Rework Building at the Naval Weapon Station, Seal Beach, CA, has been chosen as a typical example. The building is a flat roof, rectangular-shaped box with dimensions of 260 ft x 145 ft x 25 ft. The walls are constructed with 9-inch reinforced concrete, and the roof is made from corrugated sheet metal, which will probably blow off in case of an accidental explosion.

The maximum allowable explosive (Class 1.1) inside the building is 25,000-lb TNT equivalent, and it is assumed that the explosive is spherical and uniform and is located at the center of the floor.

Two upper wall sections, one for the long wall and the other for the short wall, have been chosen as the typical mesh elements for MUDEMIMP simulation. (Usually the lower wall sections will not influence the debris safety

range due to negative debris launch angles.) Each mesh element has a dimension of 24.5 ft x 12.5 ft x 0.75 ft and weighs roughly 34,453 pounds. The magnitude and the probability distribution of the debris launch characteristics for the two mesh elements have been assessed as (see Ref 3 for details):

(A) Mesh Element From Long Wall of the Building

Launch velocity (normal distribution):
mean = 270.5 fps
standard deviation = 30 fps

Launch angle (uniform distribution):
lower bound = 0 deg
upper bound = 12 deg

Debris mass (exponential distribution):
mean = 73 lb
total debris missiles = 478

Drag coefficient (uniform distribution):
lower bound = 0.47
upper bound = 1.98

Drag area, k factor (normal distribution):
mean = 1.0
standard deviation = 0.2

(b) Mesh Element From Short Wall of the Building: All parameters same except:

Launch velocity (normal distribution):
mean = 191 fps
standard deviation = 25 fps

Debris Safety Distance From Debris Missile Impact Histogram

Figures 1 and 2 are the debris missile impact histograms obtained from MUDEMIMP simulations for a mesh element on the long wall and short wall, respectively. Based on the DDESB debris hazard criterion, it is not difficult to determine that the debris safety distance for the long wall is roughly 1,300 ft, and for the short wall, roughly 820 feet. The considerably shorter safety distance for the short wall is due to a much slower debris launch velocity from being located farther from the explosion center.

Confidence Level of Debris Safety Distance

The debris missile impact histograms in Figures 1 or 2 are the output of one possible simulation corresponding to one particular test. As a consequence, the safety distances obtained for the long and short walls are also based on merely one simulation result. In order to determine a reliable safety distance for field application, it is necessary to repeat the Monte-Carlo calculation by using different "seeds" in the random number generator.

Several Monte-Carlo simulations have been tried with different cycles and "seeds." It is evident that a minimum of 50 Monte-Carlo cycles are required to establish the probability distribution, the mean, and the standard deviation of the safety distance. Nine of the sample debris missile impact histograms from the 50 Monte-Carlo cycles with different "seeds" are presented in Figure 3 for the long wall and Figure 4 for the short wall. Small variations in these histograms are clearly exhibited.

Using the predicted safety distances obtained from the 50 repeated simulations, one is able to construct a Gaussian distribution that represents the data: Figure 5 for the long wall and Figure 6 for the short wall. The mean of the safety distance is 1,264.5 ft for the long wall and 801 ft for the short wall, with a standard deviation of 66.4 ft for the long wall and 43.9 ft for the short wall. Thus, it is possible to conclude that the safety distance of the long wall will be 1,264.5 ± 66.4 ft with 68.3% confidence, or 1,264.5 ± 132.8 ft with 95.95% confidence, or 1,264.5 ± 199.2 ft with 99.7% confidence. Similarly, the safety distance of the short wall will be 801 ± 43.9 ft with 68.3% confidence, or 801 ± 87.8 ft with 95.5% confidence, or 801 ± 131.7 ft with 99.7% confidence.

Computer time for the 50 repeated Monte-Carlo simulations is not cheap, because it requires calculating 23,900 individual debris missile trajectories. However, if the runs are made over the weekend, the cost can be greatly reduced; for the long wall it costs $101.50, for the short wall, $115.50.

Most Likely Debris Hazard Area

If the wall structure is very rigid, the walls will not buckle outward before failure during an accidental explosion; the debris missiles will launch in trajectories normal to the wall. Then, theoretically, the debris hazard area will resemble a "cross" pattern as shown in Figure 7. Merz (Ref 4) from Norway has conducted some experimental tests to determine the debris hazard area; his results strongly support this "cross" pattern.

However, when the wall structure is not that rigid, the wall will bulge outward under blast pressure, and the debris missiles will launch normal to the horizontally curved walls. As a result, the debris hazard ground area will be similar to a "crucial flower" (Figure 7). The more elastic the wall structure is, the bigger and flatter the "flower petal" becomes. Eventually, the four petals of the "crucial flower" will merge with each other to form an ellipse or a circle depending on whether the building configuration is rectangular or square, respectively.

For most applications, elliptical or circular debris hazard areas are more practical to implement. Figure 7 illustrates the elliptical boundary of the debris hazard area for the sample problem. It is interesting to note that the major axis of the ellipse is in the direction perpendicular to the long wall.

MUDEMIMP Result Versus Single Debris Missile Worst Case Calculation

It has been standard practice to determine the debris safety distance based solely on the worst case calculation of a single debris missile. This ultraconservative safety practice has caused the military many operational problems due to underutilization of its limited and expensive land. With the probabilistic approach, the MUDEMIMP simulation modifies the result and reduces the encumbered land.

The worst case debris launch conditions corresponding to the sample case are as follows:

Launch velocity	=	360.5 fps (mean velocity plus 3σ)
Launch angle	=	12 deg (upper limit)
Debris mass	=	500 lb (largest debris missile)
Drag coefficient	=	0.47 (lower limit, corresponding to a sphere)
Drag area	=	1.21 (corresponding to a sphere)

Using the "TRAJ" computer program (Ref 5), the impact range of the "worst case" debris missile for the long wall is determined to be 1,537.5 ft, which is roughly 20% farther than the most likely debris safety range determined by MUDEMIMP.

Figure 8 compares the debris hazard area for the worst case prediction and the MUDEMIMP most likely prediction. The NAVSEA OP-5 standard circular debris hazard area is also shown for reference. The shaded area between the most likely ellipse and the worst case circle (and the OP-5 standard circle) is the potential saving of encumbered land area per one building; for the present case, it is roughly 97 acres (or 108%) between the worst case and the MUDEMIMP most likely prediction, and 36.3 acres (or 28.8%) between the OP-5 standard requirement and the MUDEMIMP most likely prediction.

CONCLUSIONS

1. The use of the MUDEMIMP computer program to predict debris safety distances with various confidence levels has been demonstrated.

2. The debris hazard area (ellipse) determined from the MUDEMIMP most likely prediction is only about half the size of the area from the worst case (89.8 acres vs 186.9 acres). Should the MUDEMIMP simulation be adopted in debris prediction, encumbered land within military bases will be freed for full utilization.

3. The computer usage cost for one Monte-Carlo cycle (478 trajectories) is $20 for a regular daytime run, $11 for an overnight run, and $7 for a weekend run. To repeat the Monte-Carlo simulation 50 cycles for both the long and short walls consumes approximately $217, which is truly a small amount of money when compared to experimental tests.

4. In addition to the "standard" capability of determining the debris safety distance, the MUDEMIMP simulation can also be utilized as a reliable analytical tool to study many debris hazard problems, such as building penetration, structure characteristics, safety waivers, etc.

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5. Perzel, F., et al. "Naval Explosives Safety Improvement Program (NESIP): Summary and Status Through 30 June 1976." Naval Surface Weapon Center, Technical Report TR-81-27, Silver Spring, MD, Mar 1981.

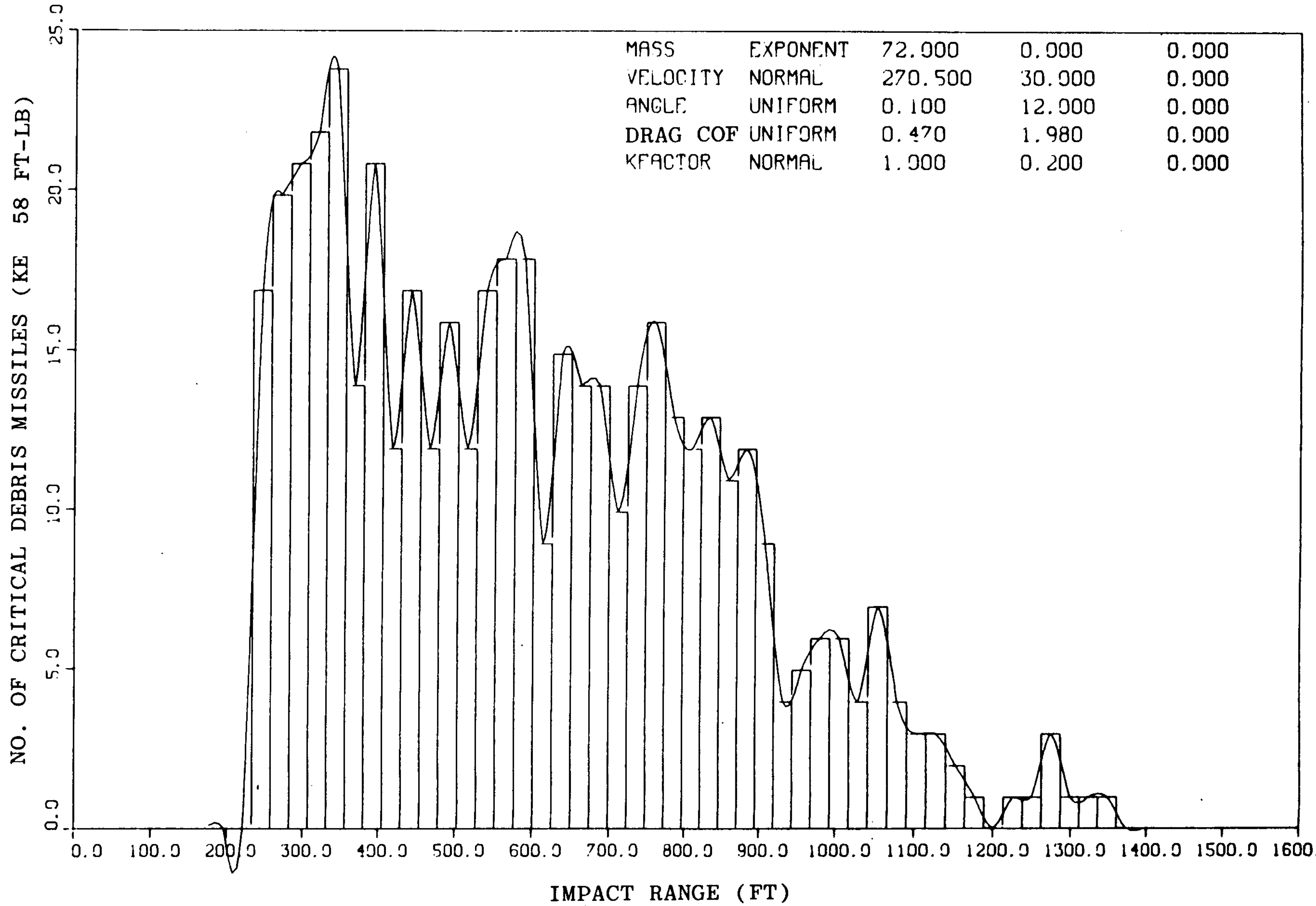


Figure 1. Debris missile impact histogram.

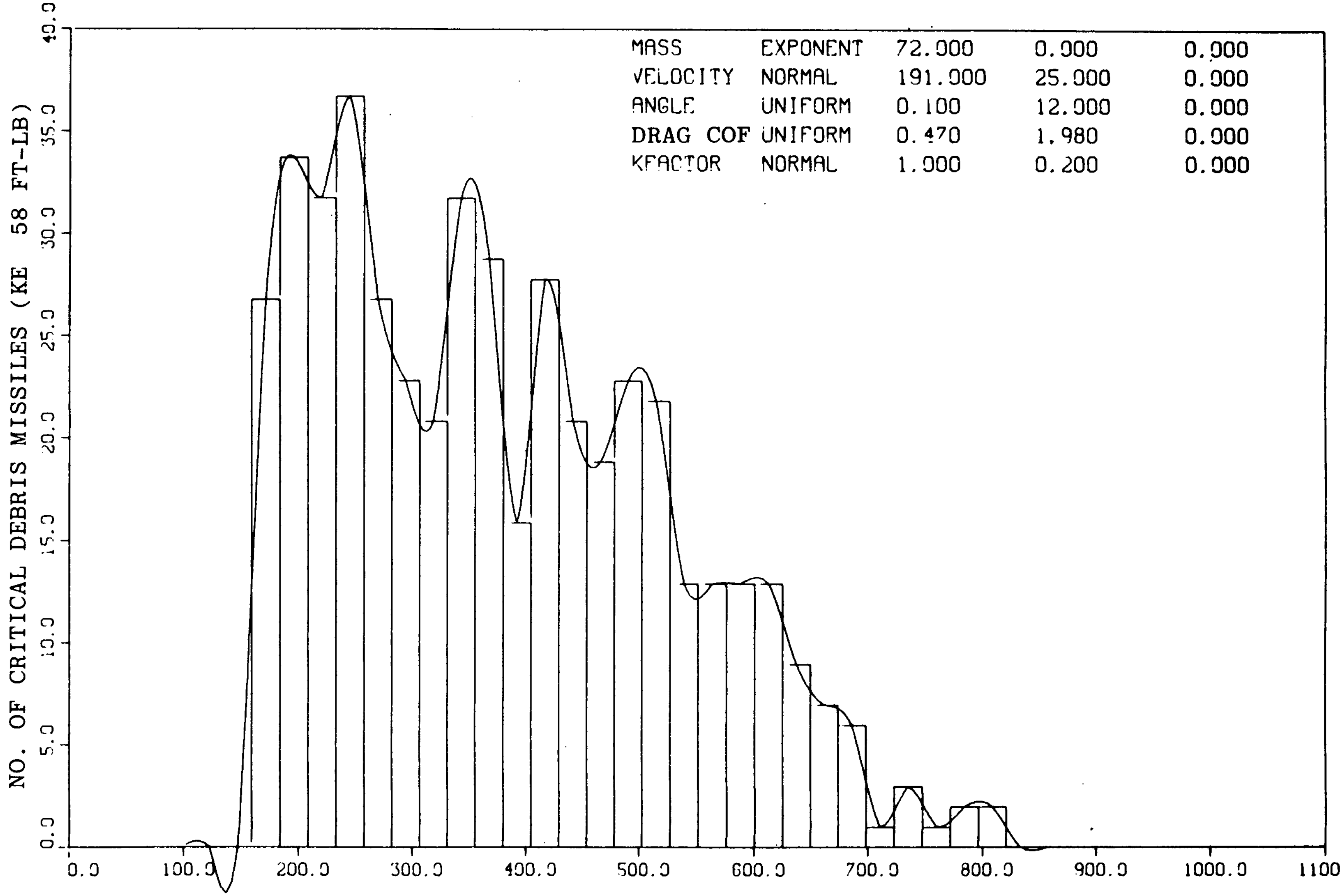


Figure 2. Debris missile impact histogram.

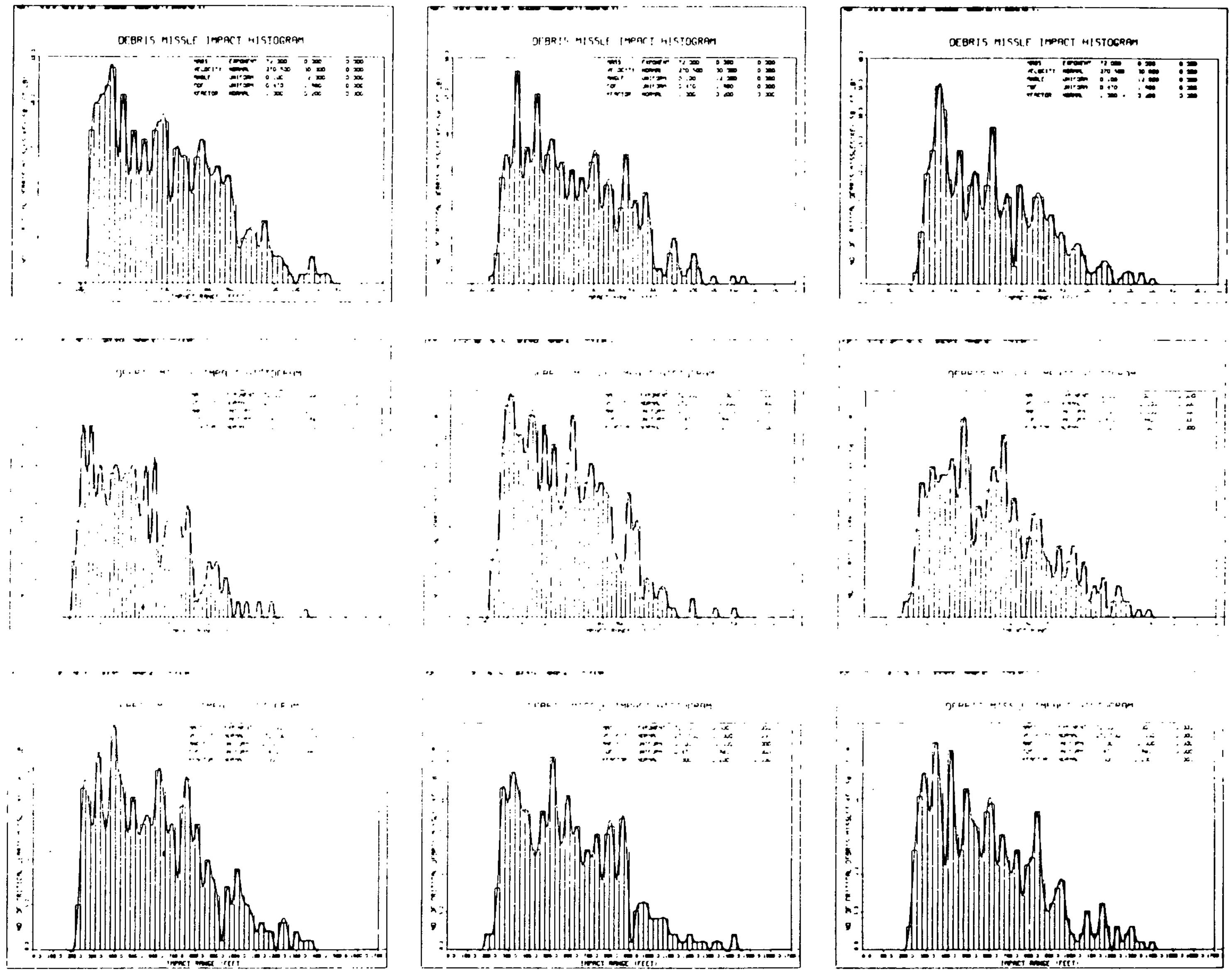


Figure 3. Histograms from repeated simulations (long wall).

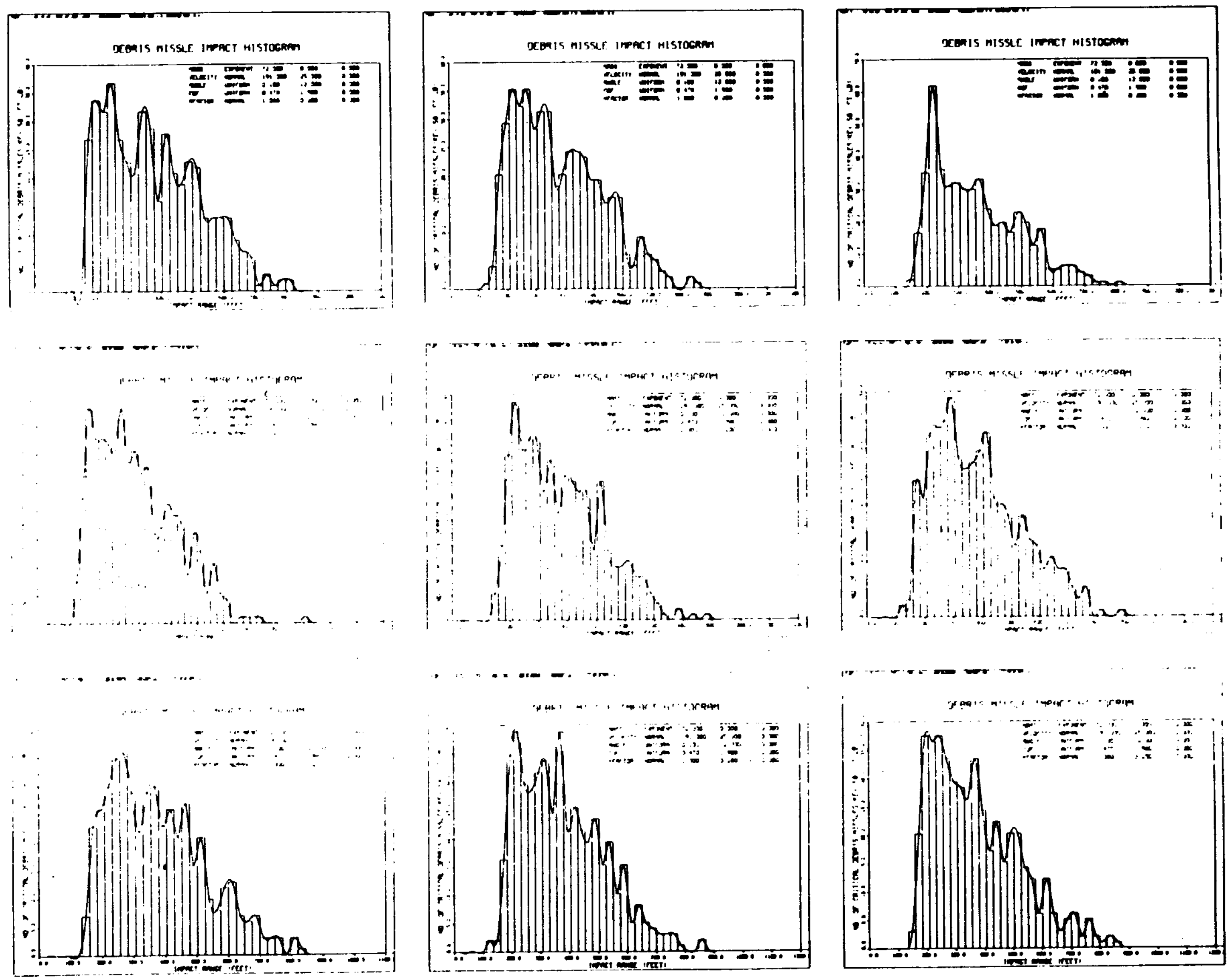


Figure 4. Histograms from repeated simulations (short wall).

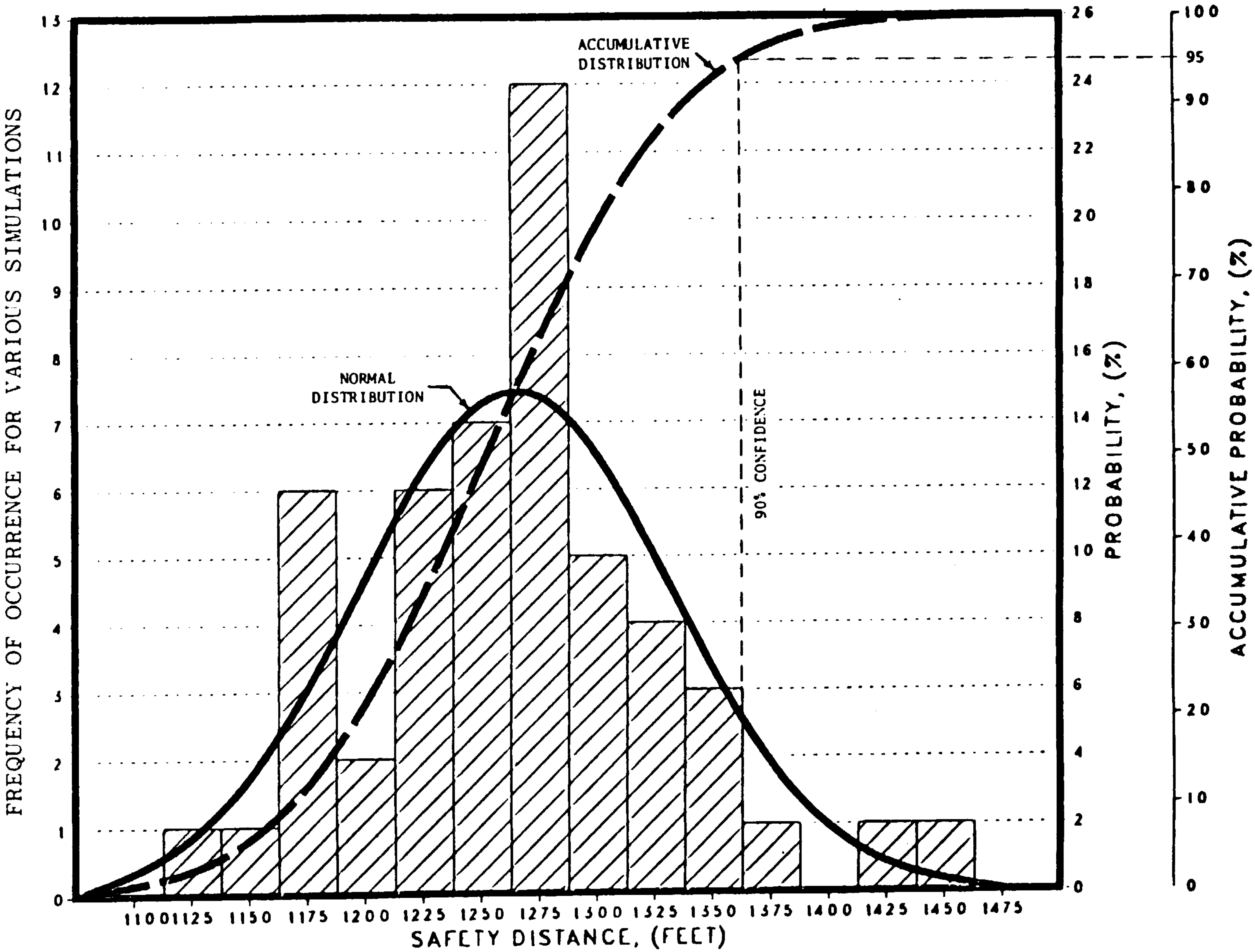


Figure 5. Safety distance distribution from various simulations (long wall).

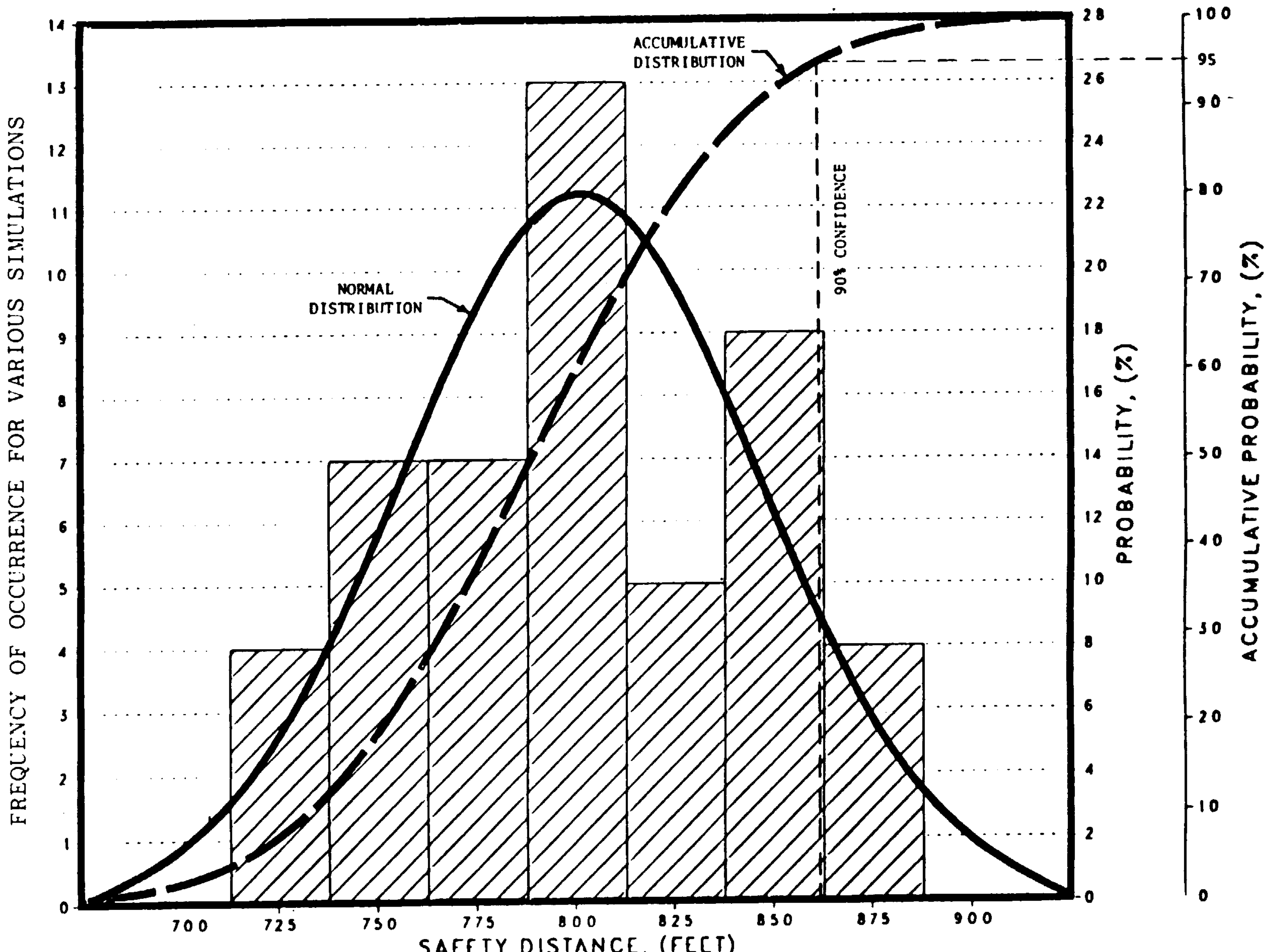


Figure 6. Safety distance distribution from various simulations (short wall).

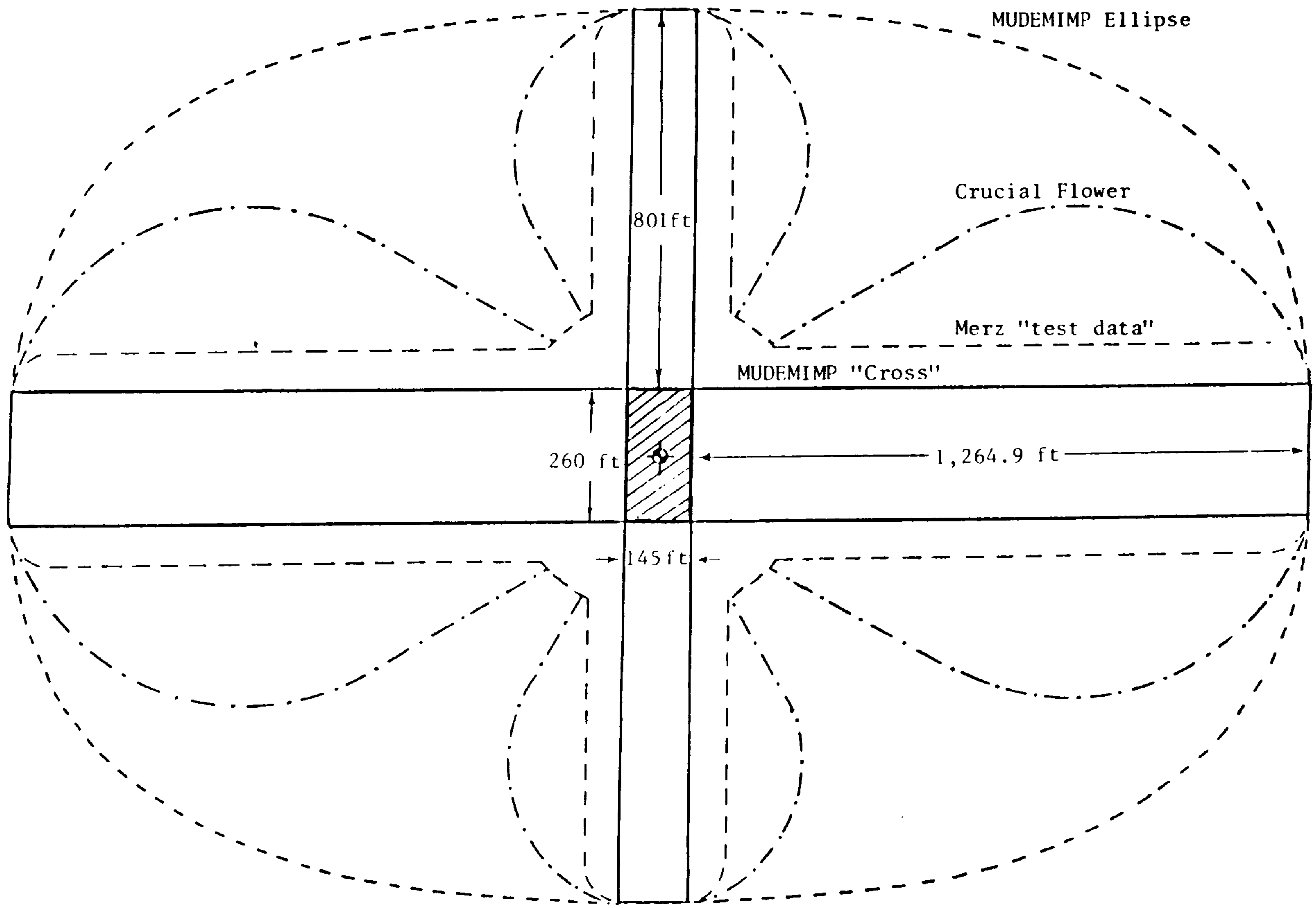
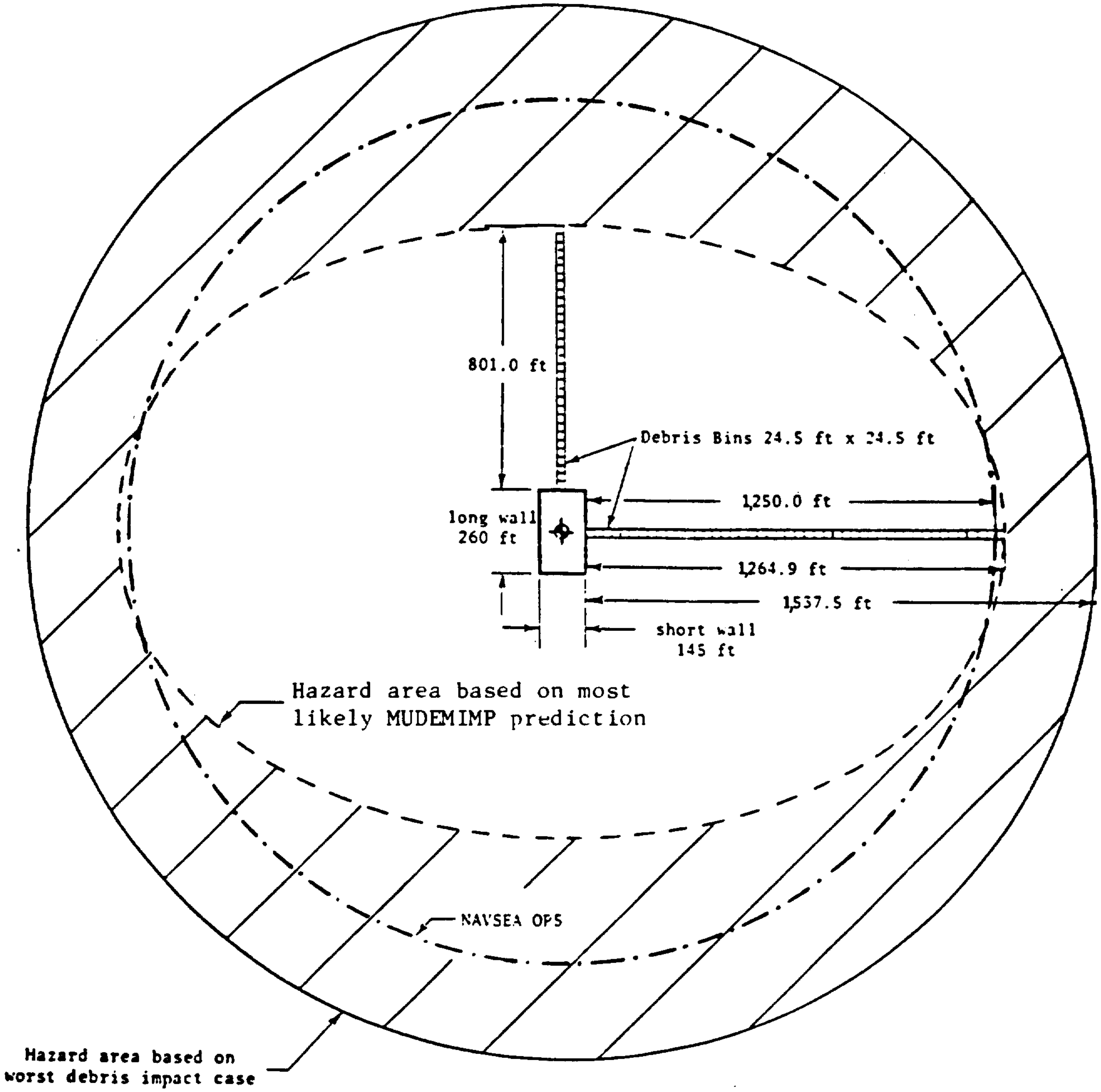


Figure 7. Pattern of debris hazard ground area.



SCALE: 1" = 500'

Most likely hazard area = 89.8 acres (28.8% smaller)
NAVSEA OP-5 standard area = 126.1 acres (baseline)
Worst case hazard area = 186.9 acres (48.2% larger)

Figure 8. Hazard area comparison for the most likely MUDEMIMP prediction, the worst possible case, and NAVSEA OP-5 standard criteria.

PAPER FOR PUBLICATION

JOINT AUSTRALIAN/UK STACK FRAGMENTATION TRIALS

PHASE I REPORT

BY

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SUMMARY

In 1980 ESTC decided to conduct a series of trials to assess the fragment throw from explosives. Because of the restrictive nature of "minimum fragment throw criteria" and the expense of building traverses, for which little credit was given, approaches were made to Australia resulting in Phase I of the trials which were fired in early 1982. The Phase I trials consisted of open stacks of bombs surrounded on two sides by traverses and a similar situation with the stack inside a building, representative of a typical UK army unit storehouse.

After the explosion, fragments and debris were collected, on a sample basis, and these were then computer sorted into a basic weight distribution with distance from the site of the explosion. These results were further refined and are presented in tabular form in the report. A detailed consideration of the fragment distribution with distance has resulted in a proposal to reduce "minimum fragment throw criteria" in the UK Quantity-Distance Tables provided the results are confirmed for smaller quantities of explosives.

Further trials have been proposed to consider this and the additional complications of different building structures.

ACKNOWLEDGEMENTS

The UK authors wish to acknowledge the major contribution made by the Australian Department of Defence to the work reported here. This work was made possible by the use of the Woomera Range and the effort provided by the Director of Trials, the Australian Army, Trials Research, and Materials Research Laboratories.

The trials were arranged through British Defence Research Scientific Staff, Canberra (Mr P G Reich and Mr J E Yeeles) with Director of Trials (Captain W Newman) and D Trials Project Manager (Major M Stanford). Main contributors to the trials were the Australian Army (Project Officer Field, Major R H Apted with EOD Staff and Captain D Taylor commanding Det 17 Construction Squadron), Trials Research Laboratories Salisbury (under F H Evans), Materials Resarch Laboratories, Melbourne (under Mr D J Hatt) and DSCW Personnel at Woomera (under Mr M King).

The experimental data was computer sorted by RARDE, Fort Halstead, UK, who also helped in the compilation of the report and the discussion of the results. The results were also discussed with the UK Ordnance Board.

The Trials proposals were discussed in detail by the UK Explosives Storage and Transport Committee.

PART I - NEED FOR AND PURPOSE OF TRIALS

1. BACKGROUND

1.1 The Explosives Storage and Transport Committee (ESTC) of the Ministry of Defence, UK, issued revised Leaflet No.5 Pt 2 on Quantity Distances (Q.D's) for Military, Explosives in June 1979 (1). These were based on tables approved by NATO. They differed in a number of aspects from those previously used, (see 7/Expls/43 Amended September 1964) (2).

1.2 In applying the new Q.D. Tables of Leaflet No.5, in addition to the application of the United Nations System for Classifying Dangerous Goods to UK Military Explosives, other changes were incorporated which posed problems. In relation to Hazard Division 1.1 Items (formerly Categories Z & ZZ), these in summary are:-

1.2.1 A traversed building containing a Net Explosives Quantity (NEQ) of 3600kg or less could no longer claim 20% reduction in the separation distance from inhabited houses, places of public assembly etc compared with the distance for a similar untraversed building.

1.2.2 No longer could a standard 2 degree traverse be considered to afford adequate screening of houses from missiles etc at less than 270 metres even where small NEQ's were involved. Indeed, the requirement to impose a minimum separation distance of 400m from built-up areas was becoming increasingly difficult to refute. In many instances the imposition of 270/400m minimum distances has severely restricted the use of buildings which had previously been licensed without undue difficulty.

1.2.3 At Outside Quantity Distances the hazard had always been identified as one of blast damage with debris playing an increasingly important role as the quantity of explosives was reduced. The acceptable risk has been defined as one lethal fragment per 600 square feet, the lethal fragment being further defined as having an energy of 58 ft. lb. (3). No experimental verification of the expected debris/fragment densities from explosions had apparently been carried out.

1.2.4 A survey of acident reports and planned test results showed that there was very little data available from which to deduce a relationship between the hazard from debris or fragments and the distance from the centre of an explosion.

1.3 The difficulties arising from the application of these minimum distances based on fragment throw in UK had also arisen in Australia, where the same Quantiy-Distance rules (1) are used. Because of these mutual difficulties a joint approach was sought to obtain sufficient data

to solve these problems.

2. PREPARATORY WORK

2.1 The need for stack fragmentation tests was agreed by the Explosion Effects Sub-Committee (EESC) of the ESTC and endorsed by the ESTC Main Committee. The then Secretary EESC (Mr Bowman) visited Australia in October 1980 and obtained a tentative approval from the Australian Department of Defence to arrange stack trials to be carried out at Woomera, South Australia, in two separate phases. Phase I involved the use of relatively small NEQ's of about 2 tonnes, to represent the largest quantity of HE usually handled in a process building. Initial proposals for Phase II were to use large stacks, of the order of 25-50 tonnes, to represent buildings and areas used for storage purposes. Final proposals would be made after the results of Phase I were assessed.

2.2 The original intention was to build up each stack using a mixture of 1,000 lb HE filled MC bombs and 5.5" HE shell from UK which were due for disposal. The prohibitive cost of sea transport from UK to Australia ruled this out and it was finally decided to use some 500 lb Minol 2 filled MC surplus aircraft bombs which were available in Australia. Whilst EESC members agreed these could not be considered as typical of modern fragmenting munitions, the high charge weight ratio was acceptable and it was deemed that allowance could be made for the Minol 2 filling. Furthermore, the revised ESTC 7/Expl/43 issued in September 1964 (2) had been modified to take into account war damage caused mainly by roughly comparable aircraft bombs.

2.3 It was agreed Phase I should be an ESTC approved trial to be carried out jointly by Australia and UK in April and May 1982 at Woomera. Proposals for the tests were approved by EESC and ESTC and are described below. A decision as to whether Phase II would be carried out at a later date would be made when the results of Phase I had been assessed.

3. AIMS OF THE TRIAL

3.1 The prime aim was to obtain data on the distribution of hazardous fragments and debris throw measured at various distances from an explosives stack or building. Phase I was intended to cover small quantities of explosives such as are used in process buildings.

3.2 From this data it was hoped that an estimate of the density of lethal fragments at various ranges could be obtained. This could then be used to verify or augment the existing Quantity-Distances based on fragment/debris throw criteria.

4. HAZARDOUS FRAGMENT CRITERIA

4.1 There are various methods of assessing the effects on personnel of fragmenting munitions. The results depend upon the criteria adopted, e.g.

skin penetration, incapacitation, death. A hazardous fragment is generally accepted to be one having an energy of 80 joules or more (derived from a value of 58ft lbs (5) dating back before World War I). This corresponds to incapacitation or worse of an individual due to his exposure to fragments of mass ranging from a few grams up to a kilogram or more.

4.2 For some years for military test purposes it has been accepted to be reasonably safe if, on average, there is not more than one such hazardous fragment deposited on 600 sq. ft. (55.7 sq. metres) of open ground. This value referred to exposed personnel, who unlike members of the public, would have no protection afforded by buildings, houses etc.

4.3 In order to decide whether a fragment meets the 80j criterion it is strictly necessary to know its mass and velocity. At the distances of prime interest ranging from say 150-500m or more, the use of strawboard packs or other means to determine striking velocities was impractical within the time and effort available for the trial.

4.4 A fragment issuing from the stack at a relatively high angle of elevation will return almost vertically with a limiting velocity dictated by its mass, shape and the air resistance it experiences. For fragments projected at low angles a mass of even a gram or so, moving at a high velocity could meet the 80j criterion. If the stack is traversed many of these low angled high velocity fragments will be intercepted by the traverse. Of those that escape, the small yet potentially hazardous fragments will, due to high air resistance, be expected to strike the ground close to rather than far from the stack. The comparison of the mass/distance distribution of fragments from a traversed and from an untraversed stack should demonstrate these features.

5. PHASE I TRIAL SPECIFICATION

5.1 The charge weight was 1757 kg NEQ for all trials. This was made up of 16 x 500 lb aircraft bombs filled with Minol 2 with a charge to weight ratio of 0.5. The bombs were arranged in the form of a cube, with each of the four vertical faces presenting the same number of noses, faces and side walls. All bombs were detonated simultaneously using PE boosters and equal lengths of detonating cord. Figure 5.1 shows the bomb orientations used for both the bare stack and building trials. The stack and traverses were oriented on the half cardinal points, i.e. NE-SW etc.

5.2 All sites were traversed on two sides. The traverse on the SW side of each site was a standard 2 degree traverse. The 2 degree elevation subtended by the traverse was measured from the top of the bomb stack. This resulted in the building on sites 3 and 4 protruding above the level of the traverse. The second traverse build on the SE side of each site subtended a 10 degree elevation from the top of the bomb stack. This traverse came up to the eaves of the building and more closely represented the normal traversing situation where the traverse height is measured from the building eaves. The remaining two sides to the SE and SW were

untraversed. Figure 5.2 shows the layout and design of the traverses.

5.3 Sites 1 and 2 had a bare stack of bombs. Sites 3 and 4, an identical stack was surrounded by a building designed to represent a UK army unit store, having a 340mm brick wall and a 150mm reinforced concrete roof. The roof was not tied to the walls and the building had a door in the middle of the NE wall. Figure 5.3 shows the building design. The loading density of explosives in the building was 59 kg per cubic metre. All four sites were in virgin,desert between 2000m and 3500m apart to ensure no overlap from thrown fragments and debris.

5.4 Areas searched for fragments and debris are shown diagrammatically in Fig 5.4 which is applicable to all sites. On all four sectors of each site a 10 degree angle was searched between distances 160-199m, 250-289m and 380-419m from the centre of the stack. Searches on a 2 degree angle were carried out in the NE and SW sectors at all other intervening distances from 100-600m. The sample areas were divided into 2m strips and the fragments and/or building debris in each strip were collected by hand. All primary fragments were tabulated according to size and weight. In the case of brick and concrete debris the total weight of brick or concrete was recorded but only the largest piece in each sampling strip was individually measured. Pieces of the roof reinforcment and the steel door cover sheet were also recorded. This search procedure was considered the best practical method due to the lack of manpower. 40-50% of the total weight of debris was collected in any area searched.

6. FRAGMENT/DEBRIS DATA ANALYSIS

6.1 The fragment data was sorted and counted by computer at RARDE, Fort Halstead and presented by sector and distance from the explosion source. Fragments were grouped into weight intervals. The trial at Site 2 was a duplication of that at Site 1, and the primary fragments collected in the corresponding areas of each site were totalled. Since the NE and NW Sector at each of these trials were identical, both being untraversed, these fragment counts were also totalled together. (See Fig.6.1). Similarly since the trial at Site 4 was a duplication of that at Site 3, the count of building debris fragments for each site were totalled. [Note that this time the NE and NW sectors were different since the NE side had a door.] (See Fig 6.2).

6.2 The areas shown in the second line of each table are the actual areas sampled. It should be noted that the areas at 160-199m, 150-289m and 380-419m are approximately 5 times any of the other areas. This was because these were searched on the 10 degree sector whereas the remainder were on a 2 degree sector.

6.3 A lethal fragment has been defined above (paragraph 4)as one having a kinetic energy greater than 80 Joules. In order to calculate the weight of such a lethal fragment it is necessary to estimate its impact velocity. Criteria currently used by ESTC in UK is that a 75g primary fragment which

has achieved its free-fall velocity before impact is lethal. Thus heavy fragments travelling on a low trajectory of less than 2 degrees at high velocity are likely to travel distances considerably in excess of several hundred metres and are unlikely to be found at the ranges we are considering. Conversely those projected on a high trajectory will have no significant horizontal velocity component at impact. Certainly on the SE and SW sectors the low trajectory high velocity fragments will have effectively been stopped by the traverse. This is still being debated within MOD. For the purpose of this report a limiting mass of 50g has been chosen as a lethal metal fragment, to give a conservative assessment.

6.4 A similar debate surrounds the choice of the limiting mass for a lethal fragment of building debris. The figure of 100g was taken on the rationale that the building debris impact velocity would be substantially less than that of the much denser primary fragments. Typically building debris impact velocities would probably be of the order of 30-40 m/sec whilst primary fragment impact velocities would be of the order of 50-70 m/sec, assuming approximate free fall.

6.5 The lethal density factor in line 3 of Figure 6.2 was used to convert the number of fragments to a "lethal fragment density". It was calculated from the following formula:

$$\text{Lethal Density Factor (LDF)} = 56/(2A)$$

where A = area in square metres actually sampled on any site. NOTE that the value of 56 comes from the US criterion of one lethal fragment per 600 square feet (56 square metres) at the Inhabited Building Distance from an explosives building. The Factor 2 in the denominator takes into account that the data was from two sites.

6.6 It must be emphasised that these masses of lethal fragments have only been used as a starting point and may need to be revised in the light of further information or study. In the table N represents the number of fragments and D the density of such fragments.

7. DISCUSSION OF RESULTS

7.1 The traverses were constructed of the local red, sandy soil and were effectively uncompacted. However, they withstood the erosive effects of the explosion surprisingly well. No significant amount of material was scoured from the surfaces of the traverses and they remained in relatively undamaged condition. The traverses were at the edge of the crater and this confirmed that removing oversize items from traverse material and compacting is not essential where relatively small quantities of HD 1.1 explosives are concerned.

7.2 Although there was not enought time available to carry out a detailed study of fragments trapped by the traverses it would appear that there was little obvious directional effects from the explosion. Fragments appeared to be fairly evenly distributed around the bottom of the traverses and in

the corners.

7.3 Figure 7.1 shows the lethal fragment density of the primary fragments over the collection range for the open stack used in sites 1/2 and Figure 7.2 for the stack in building for sites 3/4. Figure 7.3 shows the density of all lethal fragments collected on sites 3/4. It should be noted that the term density is used to mean density of lethal fragments per 56 square metres, and that any densities greater than unity are unacceptable.

7.4 In the case of open stack it would appear (Figure 7.1) that the fragment density on the traversed sides is in general less than on the untraversed sides. However the difference is small and probably not statistically significant. Fragment density at ranges beyond 600m has not been established in these trials, nevertheless it is still considered that the presence of a traverse around an open stack is beneficial and to be recommended, because it will stop the low angle, high velocity fragments.

7.5 When a building is present (Figure 7.2) it should be noted that the primary fragment levels are much higher than for an open stack at the ranges investigated and also that about 300 metres the density is barely acceptable, when no traverse is present.

7.6 Figure 7.3 shows both the combined building and bomb fragment densities and has important implications for safety. On the untraversed side containing the door (NE) the density rises steeply from 100m and peaks at 300m, reducing rapidly out to 600m. The density level is acceptable at 400m. The situation is similar in the untraversed NW sector although the actual levels are considerably less than on the NE sector. This undoubtably was caused by the presence of the door in the NE sector. This door was plated with a steel sheet, which itself produced many lethal fragments. There was also an increase in the number of primary fragments found in the NE sectors.

7.7 The situation in the other two sectors (SW and SE) shown in Figure 7.3, which are both traversed, is radically different. Firstly, there is no significant difference between the effects of the different traverse heights. Secondly there appears to be no peak in the fragment density, the level fluctuating from approximately 0.8 to 0.2 throughout the collection areas until it tails off to virtually zero at 450m and beyond. Thirdly the maximum recorded fragment density is 0.85, just below the acceptable level of 1.00. Thus it would seem that on the traversed side the choice of a 400m minimum to afford protection from debris is not supported by the evidence from these trials.

7.8 In general the presence of a traverse appears to reduce substantially the number of lethal fragments at any given range. This appears to be independent of the type of fragment or whether the traverse is 2 degrees or 10 degrees. In general there appears from these trials to have been no additional benefit accruing from the use of the larger traverse. The reduction in lethal fragments varies from 60% up to an actual increase in one or two instances, possibly caused by the orientation of the stack. On

the average the reduction is approximately 50%.

7.9 Considering primary fragments only the presence of the building effectively doubles the number of lethal fragments at any given range investigated. The effect is general and applies equally to traversed and untraversed sectors. One possible explanation is that the primary fragments reach the building walls before the blast wave had destroyed them and consequently are slowed down considerably and thereby impact the ground closer to the explosion source than had they been free flying. It should be noted that the building was totally destroyed. A lower explosive loading density in the building would perhaps increase the number of near-field primary fragments at these ranges even more due to a more effective attenuation of the explosion by the building. This could be very relevant in the light of the recommendations below.

7.10 A source of concern during the trial was the number of undoubtedly lethal door and reinforcing bar fragments. The door was a standard wooden door steel lined for security, but it gave rise to particularly nasty fragments. This is very relevant since some traversed buildings may have gaps in the traverses adjacent to the doors. Obviously the sector in front of the door requires special consideration when establishing quantity distances. The access gap in the traverse should not be immediately in line with the door. An obvious area for research is in eliminating the projection of large pieces of steel reinforcing bar. Perhaps the steel reinforcement of the concrete should be replaced by lighter bars, or carbon or glass fibre reinforcement which would not add to the lethal fragents as did the steel bars used in these roofs.

7.11 In order to give an indication of the credibility of the trials the theoretical amount of fragments and debris to be expected was compared to the actual amount collected. The following figures apply to sites 3/4 only:

% Brick (wall) recovered = 0.52%,

% Concrete (roof) recovered = 1.01%.

% Primary fragments (steel) recovered = 1.41%.

% Area sampled = 4.3% (of the total area inside 600m radius).

Since approximately 4% of the actual area was sampled the proportion of fragments/debris collected would be expected to be about this value. A large proportion of the primary fragments had been recovered, and it should be noted that no allowance has been made for the very large proportion (up to half) of primary fragments which would be projected down into the crater, whereas the proportion of concrete was lower and that of brick was very low. Since the building was totally destroyed and the brick very effectively pulverised and it is perhaps not surprising that the brick recovery was so low.

7.12 After considerable discussion with RARDE, Fort Halstead, UK concern has to be expressed as to whether the trials data is sufficiently comprehensive to immediately allow the tentative reductions in fragment/debris throw minima as outlined in Section 9. The concern arises for the following reasons:-

(i) Although the bomb stack was symmetrical, i.e. bombs nose to tail in alternate layers, the explosive event arising from the detonation of the stack is not likely to be similarly symmetrical. RARDE's view is that it is probable that more lethal fragments, both in quantity and lethality, are likely to be generated by the nose and base of the bombs, many of which may be propelled by the blast more in a line radiating through the corners of the stack than in the line normal to the sides of the stack which was sampled in the trials.

(ii) The nature of explosives stores in the stack will also have a bearing on the generation of lethal fragments. Most bomb fillings such as Minol 2 are aluminised explosives with a consequent reduction in fragment producing capacity. A similar stack of HE shell might well have given a different result.

8. CONCLUSIONS

8.1 The following are offered as provisional conclusions of the trial at this stage, to be verified by further trials, particularly in view of the RARDE reservations summarised expressed in para 7.12.

8.2 The presence of a traverse is beneficial and reduces substantially the number of lethal fragments/debris at any given range for both open stacks and buildings containing stacks.

8.3 This reduction is marked when the stack of explosives is in a brick storehouse. In this case the reduction is such that the use of a minimum debris throw distance of 270/400m is not substantiated. Therefore if sufficient protection is provided from blast by the appropriate inhabited building distance there is no need to consider debris throw as a separate hazard since adequate protection from debris will also have been provided for quantities of explosives from 1000kg to 4500kg.

8.4 The evidence from the trial does not support a reduction in outside quantity distance for debris throw from untraversed stacks or buildings. In these cases the results would appear to substantiate most of the existing standards.

8.5 The results do not allow extrapolation down to small quantities of explosives (less than 1000kg) because of the uncertainty over the way the building would break up since loading densities would then be substantially lower than the $58 kg/m^3$ used in these trials.

8.6 Additionally there is some doubt as to the applicability of the trials to buildings which are considerably weaker than those tested, e.g. with 115m brick walls. Again this is due to the uncertainty over the building break-up.

8.7 Finally we conclude that further trials (Phase II) using smaller quantities of explosives, typically of a few hundred kilograms, in a similar type brick-built building, should be carried out to verify the way this type of building breaks up. Similar trials should also be carried out to verify the situation for a brick building of lighter construction.

9. PROVISIONAL RECOMMENDATIONS

9.1 The following recommendations are offered provisionally at this stage to show the changes that might be introduced provided the data is verified by the Phase II trials (proposed in 8.7). This ramification is needed because of uncertainty about the possible variation in fragment density towards the corners of the stack used for Phase I (see para 7.12 for clarification) and the possible problems with different buildings and/or different explosives (see paras 9.5 and 9.6 for clarification) .

9.2 The trials to datehave shown that if a building, of construction similar to those tested, or an open stack, is traversed with the standard UK 2 degree traverse there appears to be no reason to apply a minimum quantity-distance of 270/400m for fragment/debris throw. The initial recommendation subject to the reservations in para 9.1 would be the use of a modified D13 distance for fragment/debris throw with a minimum of 180m as determined in ESTC Leaflet 5 Part II (1979 Edition) (1). The modification would be that for all quantities less than 4500kg the formula 5.5Q is used to calculate the required quantity-distance. This would still give adequate protection from the effects of blast.

9.3 This recommendation could be incorporated into ESTC Leaflet Part II as shown in Figures 9.1 and 9.2, which are extracts from pages 24 and 25 of the ESTC Leaflet. The principal changes are as follows:

(a) The pictogram in column (d) and Row 14 is further defined as an open stack or light-weight building up to and including one with 340mm brick walls and 150mm reinforced concrete roof. This includes buildings with walls equivalent to 9ins of concrete.

(b) Using such a Potential Explosive Site (PES) the public traffic route distances become D11 (> or = 180m) for minor routes of D13A (> or = 180m) for major routes.

(c) Using such a PES the Inhabited Building Distances become D13A (> or = 180m).

(d) A new D13A column has been included in Figure 9.2. The formula for calculating this distance is $22.2Q^{\frac{1}{3}}$ for Q > 4500kg and $5.5Q^{\frac{1}{2}}$

for Q > 450kg. No distances are quoted below 180m as this is an absolute minimum.

(e) The subscript "n" definition has been altered to read "if traverse effectively screens ES from projections, D11 or D13 to be used, as appropriate".

The above changes (a)-(e) will, if confirmed, eventually be reflected in editorial changes to the text of Leaflet 5, Part II.

9.4 In addition it is clear from Figure 7.3 that for an untraversed brick building the range of lethal fragments extends out to 350m. In the case of an open stack there is further American evidence (4,5) which suggests that 400m is required from an open stack although Fig.7.1 indicates there is no real problem. Therefore it seem appropriate to have a minimum distance of 400m fragment debris throw from untraversed stacks or buildings. This could be incorporated as shown in Figure 9.1 as follows:

(a) The pictogram in column (e) and Row 15 is defined similarly to 9.2(a).

(b) Using such a PES the public traffic route distances become D11 (> or = 270m) for minor routes and D13 (> or = 400m) for major routes.

(c) Using such a PES the inhabited Building Distances become D13 (> or = 400m).

9.5 It should be noted that if the PES in question is of weaker design, e.g. has 115mm brick walls or equivalent, or has a loading density substantially lower than the 58 kg/m^3 tested or does not contain heavily steel cased ammunition, or any combination of these circumstances, it is possible that the walls and roof will not be pulverised to the extent found in these present trials. This could lead to a larger number of hazardous building fragments at the outside quantity distances. Until further evidence is available caution should be exercised when considering outside quantity distances with such buildings at PES.

9.6 Further trials are recommended above to ascertain the extent of break up of a building holding lower quantities and to verify the use of 180m as an absolute minimum. The first trial would utilise a building similar to those already tested but holding a few hundred kilograms of explosives. The second trial would utilise a much lighter building, e.g. 115mm brick walls, but with the same quantity of explosives. It is further recommended that the HE ammunition used should be of smaller calibre than 500 lb bombs, more typical of that which would be stored in this type of building. Additional fragment collection areas, particularly in line with the stack corners, should be included.

9.7 The above recommendations are provisional until the additional experiments are completed when full review of all available data will be

carried out. This will be extended to cover other aspects which are not dealt with in this report and will include comparisons with existing data, mainly of US origin.

9.8 In view of the reservations expressed about likely fragment densities in areas not sampled in the Phase I trials it was decided that further data collection was desirable and might be possible from the original trial sites. Consequently a Phase IB pick-up was proposed and carried out during May 1984 by the Australian Army and civilian personnel assisted by the present Secretary EESC, Mr J Henderson and Mr J Walker of DSSO(PE).

9.9 The preliminary results of this Phase IB have reinforced the results obtained from Phase I and have answered the doubts expressed by RARDE in para 7.12. The new results indicate a fluctuating fragment density around the stack at any given range. The maximum debris and fragment distribution falls inside an arc 15 degrees either side of the normal to any face of the stack and it decreases substantially in the arcs centred on the corners of the stack.

9.10 The results of Phase IB which allow some corrections to the Phase I results will be published shortly as a discussion paper which will also look at the effect of varying the parameter of fragment and debris lethal weights will also be considered.

REFERENCES

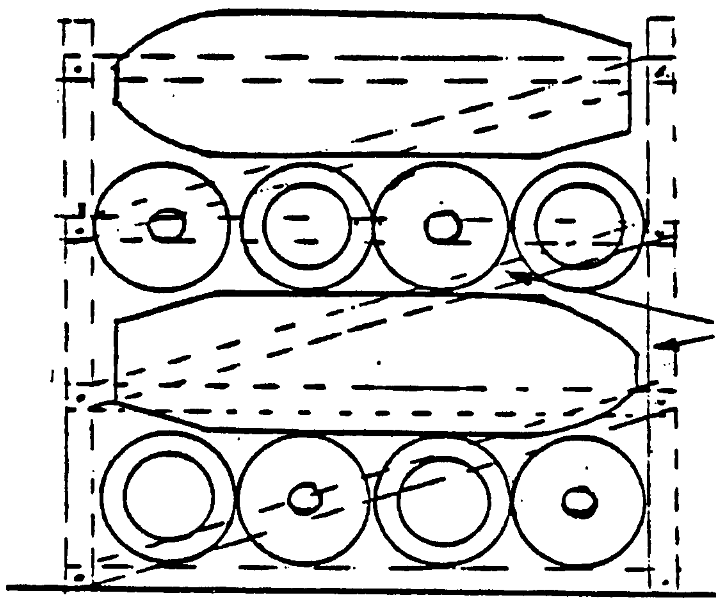
(1) Quantity Distances for Military Explosives -
ESTC/220 Leaflet No.5 - Part 2, June 1979.

(2) Safety Distances for Buildings or Stacks containing Government Explosives -
ESTC 7/Expls/43 Revised September 1964.

(3) Fragment Injury Criteria -
US(UT) - IWP/11-79 dated 28 August 1979.

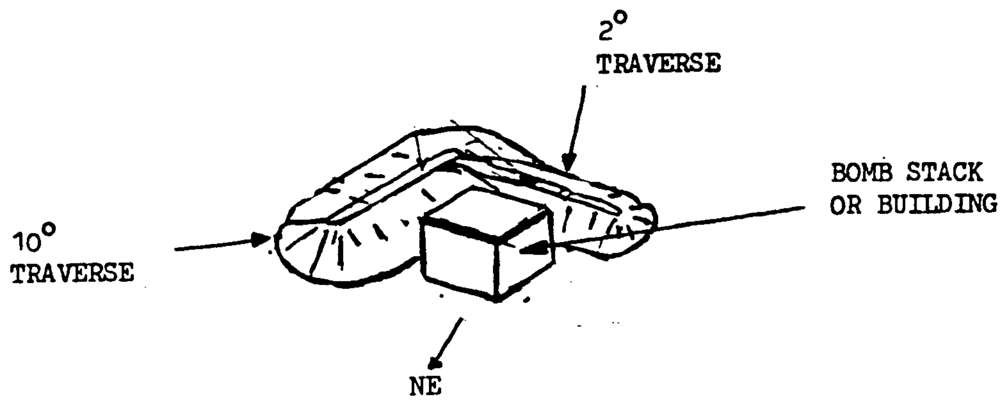
(4) Fragment Hazard Evaluations and Experimental Verification
D. I. Feinstein, 14th Explosives Safety Seminar

(5) Fragment Hazard Investigation Program
R. T. Ramsey et al, 18th Explosives Safety Seminar

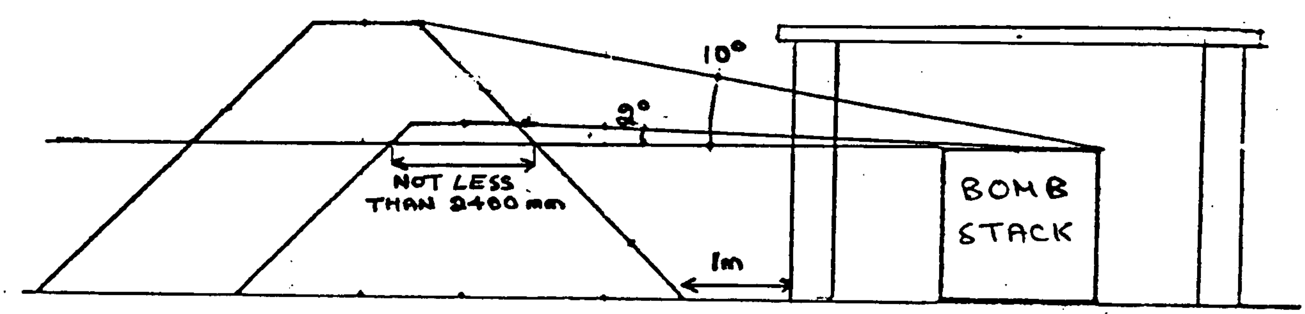


16 BOMBS ARRANGED IN FOUR LAYERS OF 4 TO GIVE ON EACH VERTICAL FACE SAME NUMBER OF NOSES AND BASES.

Figure 5.1

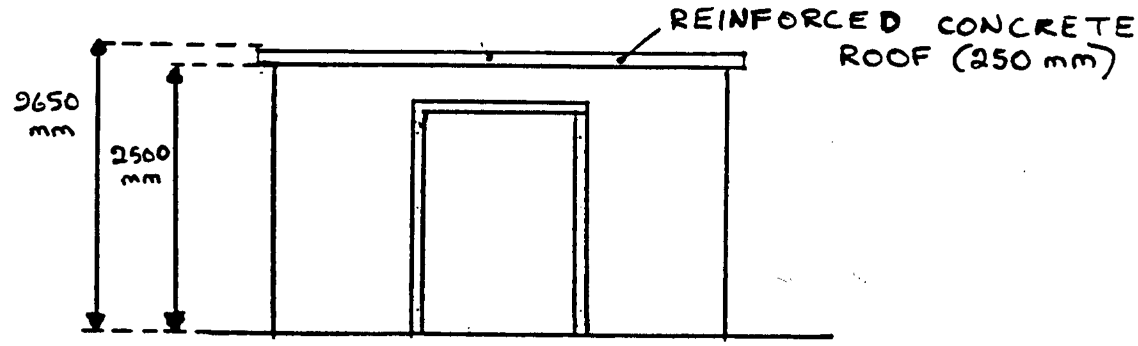


TRAVERSE ORIENTATION

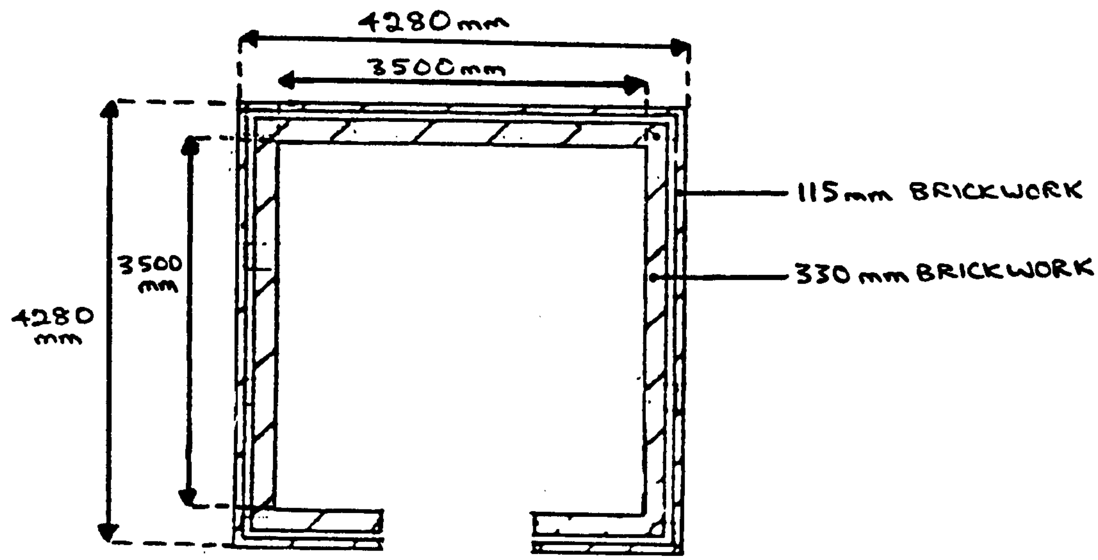


TRAVERSE DESIGN

Figure 5.2



FRONT ELEVATION



PLAN

Figure 5.3

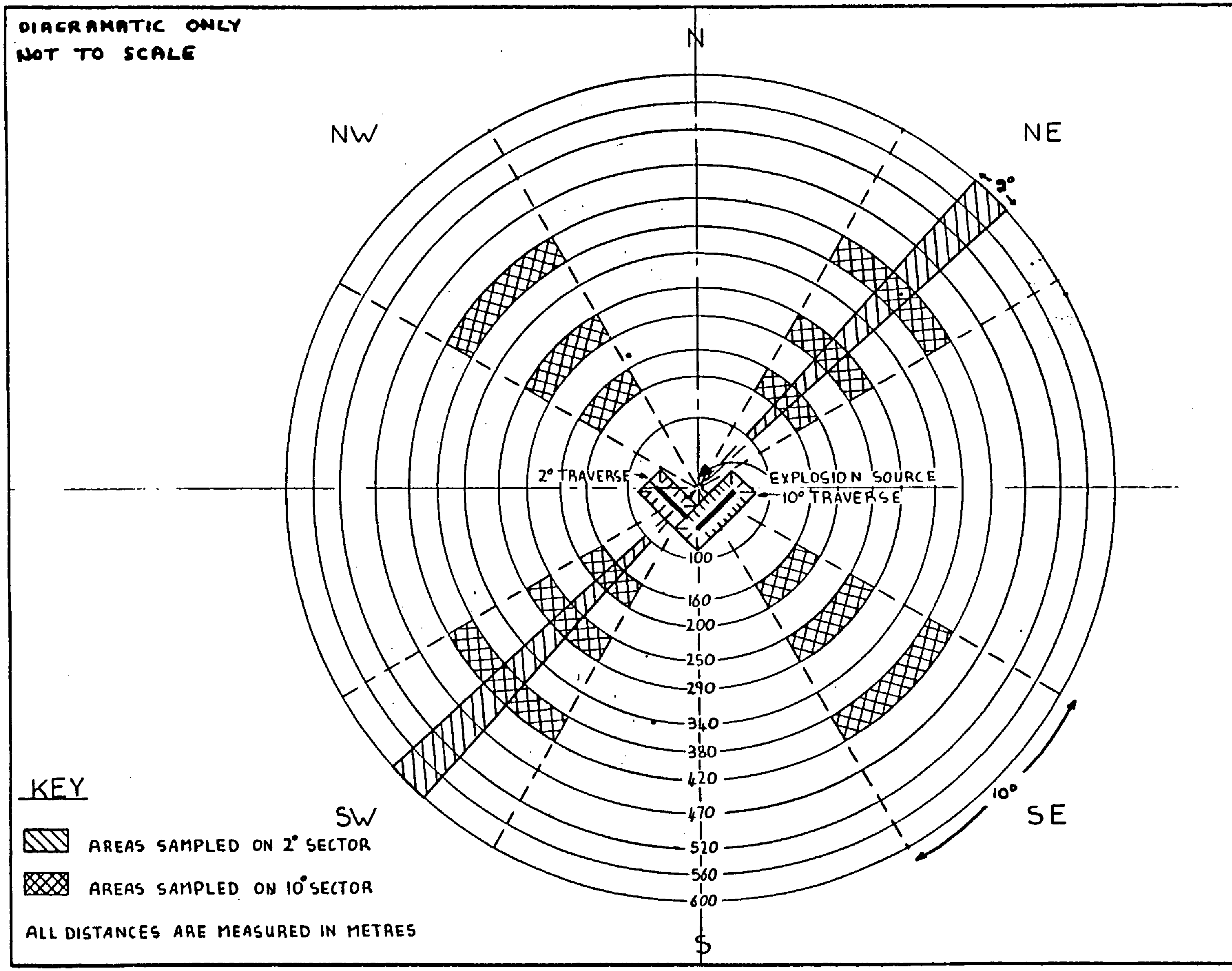


FIGURE 5·4
SAMPLING
AREAS

81

SITE 3/4 TABLE 43: ALL FRAGMENTS: ALL METAL > 50G: ALL MASONARY > 100 g.

DISTANCE (m)		100-159	160-199	200-249	250-289	290-339	340-379	380-419	420-469	470-519	520-559	560-600
AREA (sq.m)		272*	1255‡	393*	1885‡	550*	503*	2795‡	777*	864*	754*	810*
LETHAL DENSITY FACTOR		0.1029	0.0223	0.0713	0.0149	0.0509	0.0558	0.0100	0.0360	0.0324	0.0371	0.0346
NE	N		55		80			44				
10°	D		1.227		1.192			0.440				
NE	N	5		11		41	14		3	5	6	0
2°	D	0.515		0.784		2.087	0.780		0.468	0.162	0.223	0
NW	N		26		66			45				
10°	D		0.580		0.983			0.450				
SE	N		27		58			22				
10°	D		0.602		0.864			0.220				
SW	N		23		52			30				
10°	D		0.513		0.775			0.300				
SW	N	5		6		5	11		1	2	1	0
2°	D	0.515		0.428		0.153	0.613		0.036	0.065	0.037	0

* 2° Sector Area ‡ 10° Sector Area

N = Number of Fragments D = Lethal density per square metre

Figure 6.1

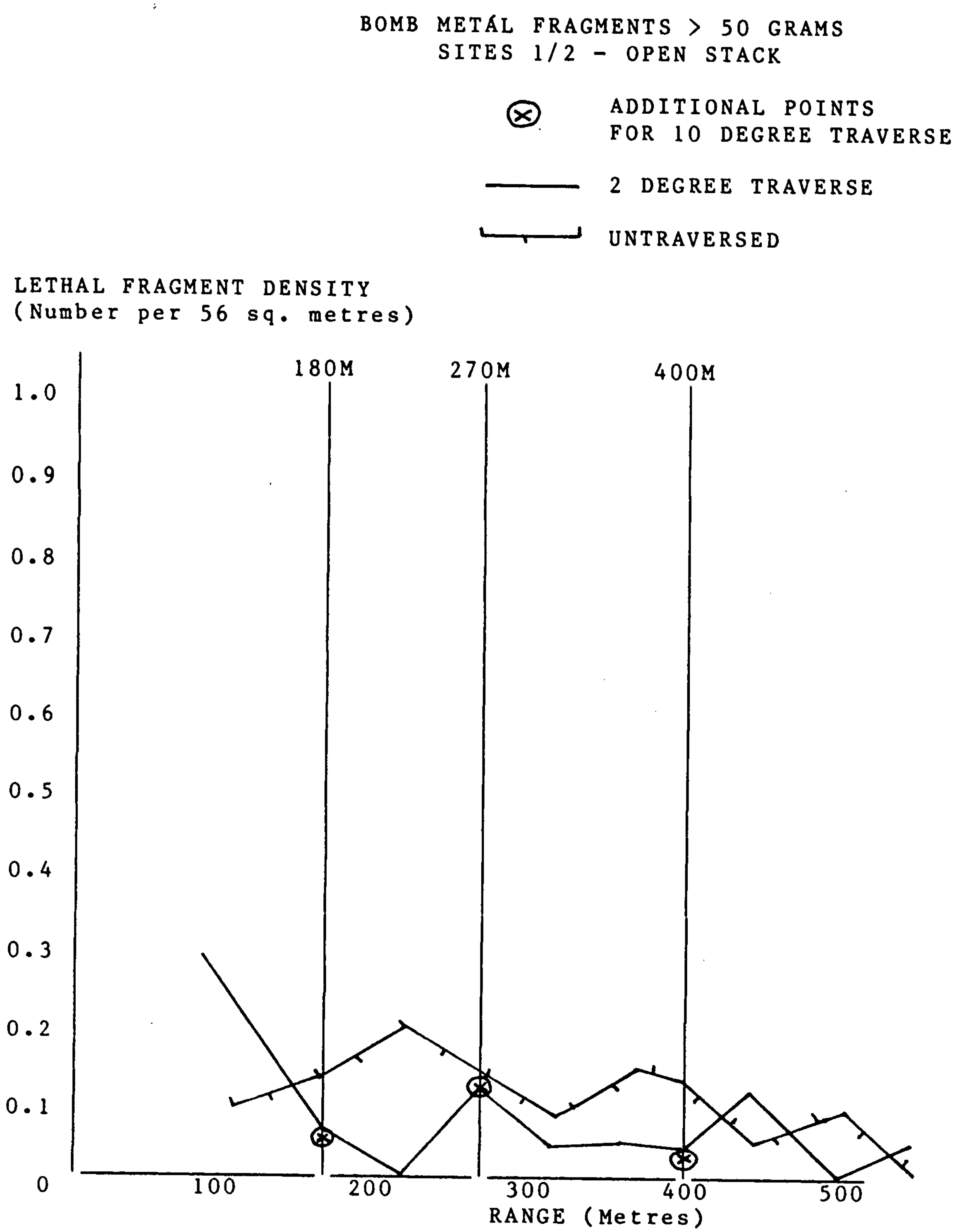
SITE 1/2 TABLE 37: BOMB METAL FRAGMENTS OVER 50G

DISTANCE (m)		100-159	160-199	200-249	250-289	290-339	340-379	380-419	420-469	470-519	520-559	560-600
AREA (sq.m)		272*	1255 ‡	393*	1885 ‡	550*	503*	2795 ‡	777*	864*	754*	810*
LETHAL DENSITY FACTOR		0.1029	0.0223	0.0713	0.0149	0.0509	0.0558	0.0100	0.0360	0.0324	0.0371	0.0346
NE NW 10°	N		14		20			31				
	D		0.156		0.149			0.155				
NE 2°	N	1		3		2	3		1	3	0	2
	D	0.103		0.214		0.102	0.167		0.036	0.097	0	0.069
SE 10°	N		3		8			3				
	D		0.067		0.119			0.030				
SW 10°	N		4		8			5				
	D		0.089		0.119			0.050				
SW 2°	N	3		0		1	1		4	0	1	0
	D	0.309		0		0.051	0.056		0.144	0	0.037	0

* 2° Sector Area

‡ 10° Sector Area

Figure 6.2



BOMB METÁL FRAGMENTS > 50 GRAMS
SITES 1/2 - OPEN STACK
ADDITIONAL POINTS FOR 10 DEGREE TRAVERSE
2 DEGREE TRAVERSE
UNTRAVERSED
LETHAL FRAGMENT DENSITY (Number per 56 sq. metres)
180M
270M
400M
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
100
200
300
400
500
RANGE (Metres)

FIGURE 7.1

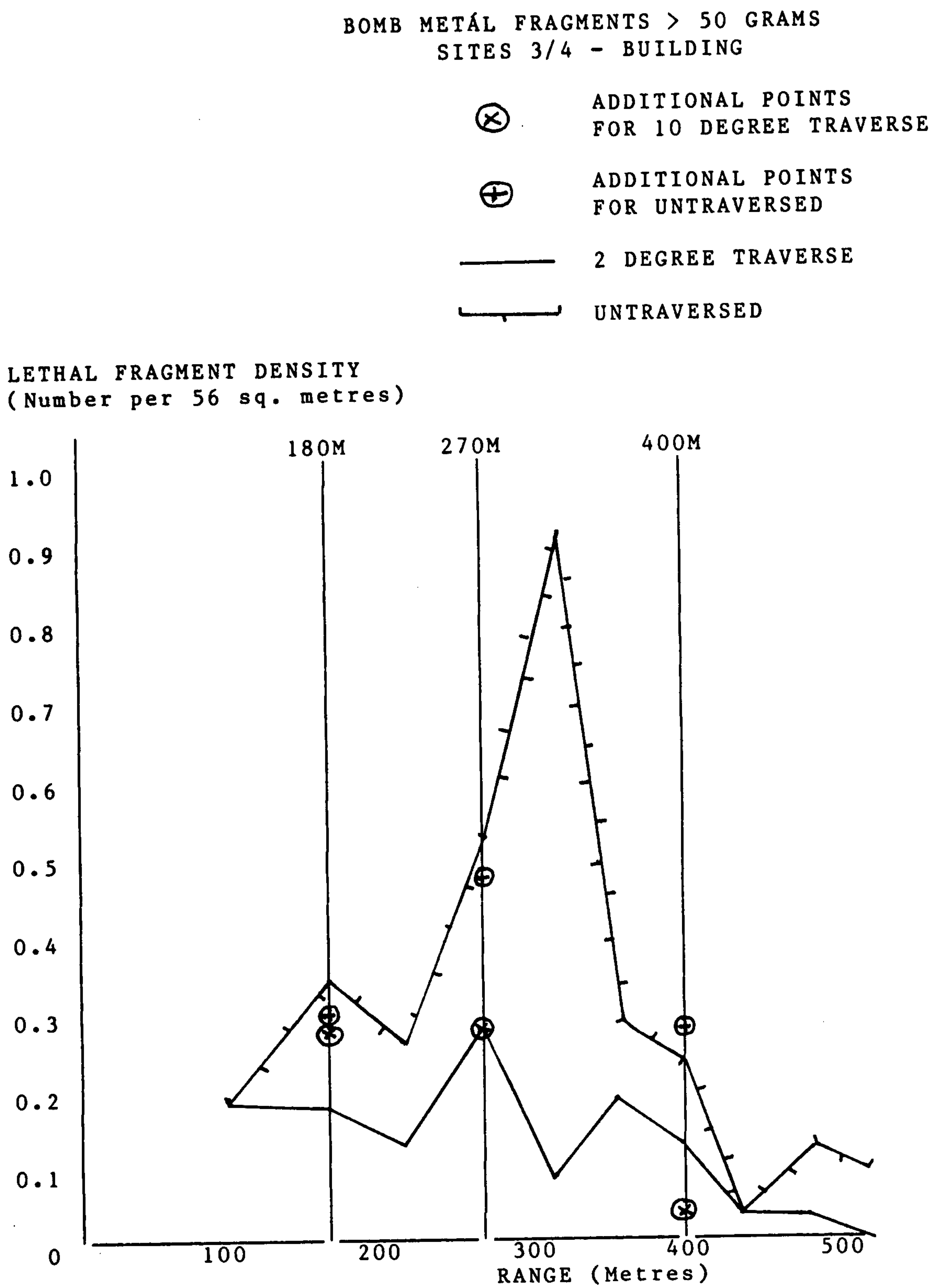
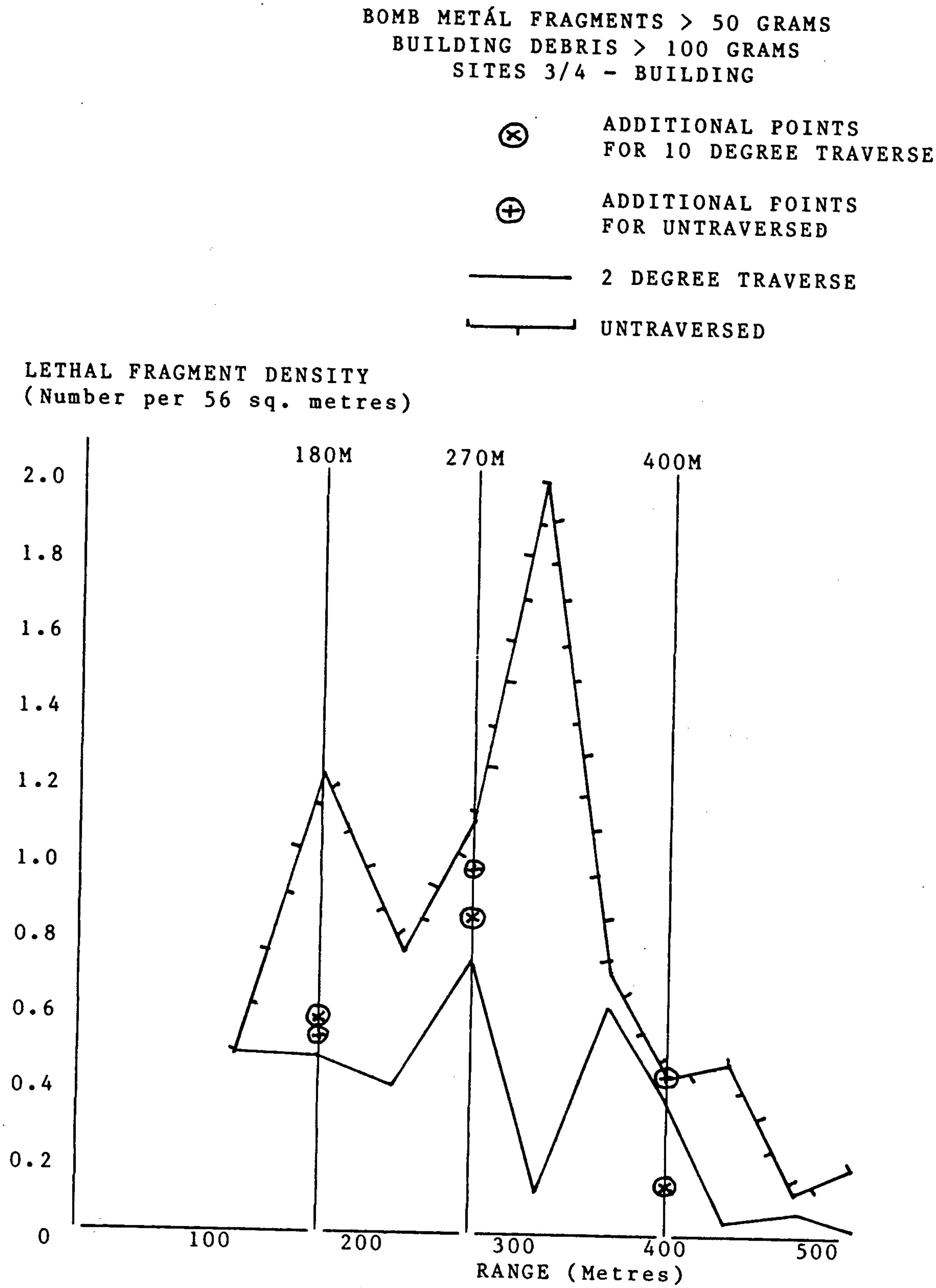
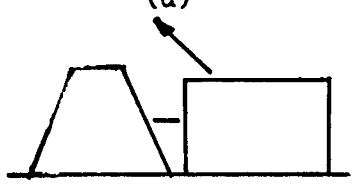
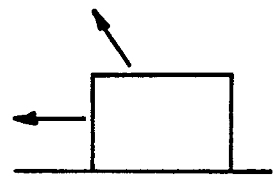
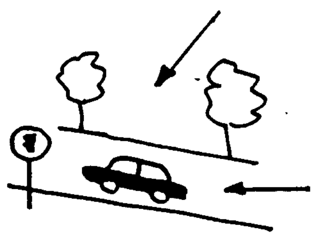
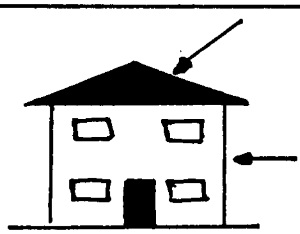

BOMB METÁL FRAGMENTS > 50 GRAMS
SITES 3/4 - BUILDING
ADDITIONAL POINTS FOR 10 DEGREE TRAVERSE
ADDITIONAL POINTS FOR UNTRAVERSED
2 DEGREE TRAVERSE
UNTRAVERSED
LETHAL FRAGMENT DENSITY
(Number per 56 sq. metres)
180M
270M
400M
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
100
200
300
400
500
RANGE (Metres)

FIGURE 7.2



BOMB METÁL FRAGMENTS > 50 GRAMS
BUILDING DEBRIS > 100 GRAMS
SITES 3/4 - BUILDING
ADDITIONAL POINTS FOR 10 DEGREE TRAVERSE
ADDITIONAL POINTS FOR UNTRAVERSED
2 DEGREE TRAVERSE
UNTRAVERSED
LETHAL FRAGMENT DENSITY
(Number per 56 sq. metres)
180M
270M
400M
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
100
200
300
400
500
RANGE (Metres)

FIGURE 7.3

POTENTIAL EXPLOSION SITE / EXPOSED SITE	(d) 	(e) 
19 	D11 ($\geq$ 180m)$_{kn}$ or D13A ($\geq$ 180m)$_{n}$	D11($\geq$ 270m)$_{k}$ or D13 ($\geq$ 400m)
20 	D13A ($\geq$ 180m)$_{ln}$	D13 ($\geq$ 400m)$_{l}$

k: reaction of drivers on busy roads.

l: flying and falling glass etc.

n: if traverse effectively screens ES from projections, D11 or D13 to be used as appropriate.

Figure 9.1

Net explosives quantity Q	Quantity-Distances	
	D13	D13A
500	95	180
600	110	180
700	120	180
800	130	180
900	140	180
1 000	150	180
1 200	170	195
1 400	190	210
1 600	210	220
1 800	225	235
2 000	240	250
2 500	280	280
3 000	305	305
3 500	330	330
4 000	350	350
5 000	380	380
6 000	405	405
7 000	425	425
8 000	445	445
9 000	465	465
Distance Functions	$D13 = 1.5\ Q^{2/3}$ for Q 2500 $D13 = 5.5\ Q^{\frac{1}{2}}$ for Q 4500 $D13 = 22.2\ Q^{\frac{1}{3}}$ for Q 4500	$D13A = 5.5\ Q^{\frac{1}{2}}$ for Q _ 4500 $D13A = 22.2\ Q^{\frac{1}{3}}$ for Q 4500

Figure 9.2

METHODS OF QUANTITATIVE RISK ASSESSMENT:
THE CASE OF THE PROPELLANT SUPPLY SYSTEM

by

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ABSTRACT

As a consequence of the disastrous accident in Lapua (Finland) in 1976, where an explosion in a cartridge loading facility killed 40 and injured more than 70 persons, efforts were undertaken to examine and improve the safety of such installations. An ammunition factory in Switzerland considered the replacement of the manual supply of propellant hoppers by a new pneumatic supply system. This would reduce the maximum quantity of propellant in the hoppers to a level, where an accidental ignition would no longer lead to a detonation, and this would drastically limit the effects on persons.

A quantitative risk assessment of the present and the planned supply system demonstrated that, in this particular case, the pneumatic supply system would not reduce the risk enough to justify the related costs. In addition, it could be shown that the safety of the existing system can be improved more effectively by other safety measures at considerably lower costs.

Based on this practical example, the paper demonstrates the advantages of a strictly quantitative risk assessment for the safety planning in explosives factories. The methodological background of a risk assessment and the steps involved in the analysis are summarized. In addition, problems of quantification are discussed.

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21st DoD Explosives Safety Seminar, 28-30 August 84
Hyatt Regency Hotel, Houston, Texas, USA

INTRODUCTION

In 1976 a disastrous accident occurred in the ammunition factory of Lapua in Finland (Ref. 1). In the department for the loading of cartridges of small arms ammunition, propellant ignited in a feeding unit of the loading machine. This led to the detonation of an above-located hopper which subsequently propagated to the other hoppers and propellant drums located on the powder loft. A total of approximately 700 kg of gun propellant detonated and destroyed the building. 40 of the 69 persons working in the building at the time of the explosion were killed, and more than 70 were injured. Heavy damage was caused to the buildings in the vicinity.

The reason of the accidental ignition could not be proved for certain. However, it was clearly stated that a number of different factors such as the considerable quantity of powder in the powder loft, the direct connection between the loading machines and the hoppers on the powder loft, the insufficient information about the risk of a detonation, and such as the large number of persons in the building have contributed to the disastrous consequences of this accident.

In reconstructing the loading department, a number of safety measures were realized, amongst which a pneumatic supply of small propellant charges coming from a separate storage building to the loading machines, is the most important one.

This accident gave rise to an examination of the safety of similar installations in Swiss ammunition factories. After some immediate safety measures - derived from a purely qualitative analysis - had been taken, the question remained whether the present manual supply should be replaced by a similar pneumatic system as in Lapua. The related costs were estimated to amount to almost 2 million Swiss Francs. Since this investment would not be justified from an operational point of view, and since it is planned to give up this particular production in foreseeable future, the problem boiled down to the question whether the **gain in safety** would justify this **investment.**

STATEMENT OF PROBLEM

Figure 1 schematically shows the present arrangement in the building, where five loading machines are located, and where more than 30 persons are engaged in loading, packing and other related operations. The propellant is supplied in closed aluminum drums of 50 kg each to a special storage room, where up to 8 drums, or 400 kg, of propellant can accumulate. 5 of them are placed upside down on special feeding hoppers. From these, jugs with a capacity of 8 kg each are filled manually. Through special openings they are brought into the building and to the hoppers of the loading machines. The propellant quantity in the hoppers is kept between 10 and 20 kg, marked

on the hopper, by the persons in charge. In contrast to the arrangement in Lapua prior to the accident, therefore, no direct connection between the loading machines and the feeding hoppers exists, and the total amount of propellant in the building is much smaller.

Figure 2 schematically shows the proposed arrangement for the pneumatic supply system. At some distance from the building, a new storage building was planned, where 8 hoppers with a capacity of 50 kg each are connected to the supply system. In addition, 6-8 drums were required to ensure continuous operation. From these hoppers, charges of about 500 grams of propellant would be transported to a cyclone above the loading machines. As soon as the propellant quantity drops below 300 grams, a new charge is delivered automatically. Therefore, the quantities in each hopper on the loading machine is reduced from the present 10-20 kg to 300 - 800 grams.

It is quite obvious that the drastic reduction of the propellant quantities in the hoppers above the loading machines would increase the safety of the facility. However, it is not at all obvious if, in this particular case, the gain in safety justifies the investment. In this situation the following three questions were raised (see Figure 3):

1. What is the **risk involved in the present loading operations,** and can it be considered acceptable?

2. What is the **risk of the pneumatic system** and how does the risk reduction compare to the cost?

3. Are there **alternative safety measures** which could reduce the risk more effectively at lower costs?

APPLIED METHODOLOGY

In order to answer the above mentioned questions, a risk analysis has to be performed, where risk is defined as the expected damage to persons due to accidental events and is a function of its probability of occurrence and its consequences.

For a full description of the risk situation both **individual risks** and **collective risks** have to be calculated (see Figure 4).

. An individual risk can be calculated for each person who might be affected by an event. It is the probability (e.g. per year) that a specific person will be killed due to this potentially hazardous activity. It is the product of the probability

- w_E, that an event occurs (e.g. per year)
- t, that the specific person is present, and
- λ, that he will be fatally injured.

- The collective risk is the sum of all individual risks. It is equal to the expected total number of fatalities (e.g. per year) due to this potentially hazardous event [1].

In an explosives factory persons are, typically, exposed to more than one hazardous event. The total individual risk is therefore composed of the individual risks of each event. In such complicated cases it proves to be most beneficial to use a so-called **risk matrix** to show the full range of the individual and collective risks (see Figure 5): Each square of the matrix contains the individual risk r_{ij} of person P_i due to event E_j. Adding up vertically over all events yields the total individual risks r_i of the exposed persons, and the horizontal sum yields the total collective risks R_j of the various events.

The overall collective risk R due to all events together is obtained either by summing the total collective risks R_j of all events or by adding up the total individual risks r_i of all persons.

This presentation of the risk situation has proved to be a most powerful tool for identifying and analyzing safety problems and the benefit of safety measures.

In order to find the values of the different elements of the risk matrix, a risk analysis is performed. It consists of the following four steps (see Figure 6):

- In the **event analysis** the type of reaction (e.g. fire, deflagration, detonation), the location, the size and the probability of occurrences and propagation of all possible events are assessed.

- In the **effect analysis** the physical effects on persons and objects in the vicinity are computed.

- In the **exposure analysis** the spatial and temporal presence of persons is investigated.

- In the **risk calculation,** finally, the different risk values are computed.

The risk matrix is the basis for the assessment of the acceptability of the risk situation (see Figure 7). For individual risks, the responsible authorities have fixed an acceptable value of $3 \cdot 10^{-4}$ per year for workers in explosives factories. Values above are not considered acceptable and require corrective action. The collective risks are assessed on the basis of cost/benefit considerations. A collective risk value is considered acceptable in the case of an explosives factory, if it can be demonstrated that

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1) In some situations it is necessary to additionally calculate a perceived collective risk to account for the aversion against accidents with a large number of fatalities (see Ref. 2).

the next most effective safety measure requires more than 3 million Swiss Francs (approx. 1.5 Mio US Dollars) to save an additional human life (willingness-to-pay approach). It can be shown that this criterion only can provide an optimal distribution of the safety costs (see Ref. 3).

RISK ANALYSIS OF THE MANUAL AND THE PNEUMATIC SUPPLY SYSTEM

The **event analysis** usually is the most complicated and time-consuming step of the risk analysis. Whereas the location of events and the explosives quantities involved can often easily be determined, the assessment of the type of reaction and the quantification of the probability of occurrence and of propagation represent a much more complex problem.
As an example, Figure 8 shows the location of the identified (and independent) sources of events in the manual supply system. They correspond to the location of the feeding hoppers in the storage room and of the hoppers above the loading machines. For each possible event the maximum possible quantity of propellant has been assumed.

For the assessment of the probability of occurrence of events during fabrication, transport and storage of ammunition and explosives a systematic and quantitative scheme has been developed during the last ten years. The quantitative estimates have been obtained from a combination of statistical data, theoretical investigations and judgement of explosives experts. This scheme, which cannot be explained in full details here, is continuously updated, when new data or investigations are available.

In the analysis of the propellant supply systems it had to be assumed that all possible events most probably start as a fire. The assumed probabilities of occurrence are listed in Figure 8 for the various operations involved. For the sake of comparison each probability value is defined for a reference duration of 1 year (8760 hours) of continuous operation.

Since a transition of a fire to a deflagration/detonation is basically possible in the types of propellants used in this ammunition, and propagation of a fire and of detonations are also possible, corresponding quantitative estimates of transition and propagation probabilities had to be made. Figure 9 schematically shows some of the considered transition and propagation events in the manual supply system and the assumed probability values. The assumptions were based likewise on test results, theoretical investigations and professional judgement.

From this analysis a total of 19 different events, or chains of events, were identified for the manual supply system. They differ in the type of the reaction, the propellant quantities involved and in the assumed probabilities. For the pneumatic supply system only two events in the storage room had to be distinguished, since events in the cyclones and hoppers above the loading machine could be neglected due to the small quantities of propellant.

For each of the identified events an **effect analysis** was performed. The procedure is defined in detail in manuals and regulations, which were prepared earlier for Swiss authorities (Ref. 4).

Figure 10 shows an example of lethality zones for the detonation of 800 kg of propellant in the storage building of the pneumatic supply system. The zones combine the effects of the fireball, airblast and the debris throw. According to the latest investigations of debris disposal, reported to the DDESB seminar in 1980, directional effects have been included.

In the **exposure analysis** the exact location of persons and their temporal presence in the loading building and the vicinity was determined.

In this particular case, the **risk calculations** did not have to be presented in the form of a risk matrix. It could be shown that the individual risks of all exposed persons were lower than the acceptable value mentioned earlier and at about the same level. Therefore, the discussion could concentrate on the total collective risks of the two supply systems.

The results of the quantitative risk analysis are shown in a risk/cost diagram in Figure 11. For the present manual supply a total risk of $6.7 \cdot 10^{-2}$/year and for the pneumatic system of $1.5 \cdot 10^{-2}$/year was calculated. Therefore, the pneumatic system with estimated costs of about 2 Mio Swiss Francs. can decrease the risk by about 80 %. Under the assumption of a lifetime of 25 years for this new system, a mean expected value of about 1 human life could be saved with this safety measure in this period.

Though the afore-mentioned willingness-to-pay criterion of 3 Mio Swiss Francs for each saved life would not basically forbid this investment, the question remained if the safety could not be improved more effectively by other safety measures. In order to answer this question, the contributing factors to the collective risk of the manual supply system have to be analyzed. Figure 12 shows the contribution in percentage of the various events. According to this, 72 % of the collective risk are produced by detonation events in the storage room, whereas the rest is produced mainly by detonation events in the hoppers of the loading machines. By preventing these detonation events, the collective risk could be decreased by 98 %. Technical investigations demonstrated that measures for preventing a detonation in the drums of the storage room and in the hoppers of the loading machines can be realized at cost of 200 to 400'000 Swiss Francs. In the meantime, a non-detonable propellant drum was developed and successfully tested.

Preventing detonations of the propellant is a safety measure which applies to the new storage room of the pneumatic supply system as well. The risk of this system can therefore be reduced with small additional costs, too.

The risk reduction and the estimated costs of these two alternative safety measures and the improved pneumatic supply system are plotted in the risk/cost diagram in Figure 13. It is readily apparent that the two measures for the manual supply represent a more effective and more economic alternative, since the risk can be decreased at considerably lower costs. A further risk

reduction which would involve, for instance, the protection of the persons against accidental fires in the storage room and the hoppers, did not prove to be justified according to the criteria for collective risks.

SUMMARY AND CONCLUSIONS

On the basis of a quantitative and systematic risk assessment of the two propellant supply systems it could be demonstrated:

- that, according to the defined safety criteria, safety measures are required to reduce the risks of the manual supply system,

- that the originally planned pneumatic supply system is not justified, because the risk reduction is not large enough in comparison to the required investment,

- that the safety can be enhanced more effectively and at lower cost, if the powder drums and the hoppers above the loading machines are modified so that detonations can be prevented.

Both these safety measures are presently being realized.

It is important to note that the conclusions reached in this specific investigation are not generally valid. In this particular case, two special conditions proved to be most important: (1) The fact that no direct connection existed in the manual supply between the storage room and the hoppers above the loading machine. Therefore, an ignition in the loading machine, which is the most likely event, will usually have limited effects. (2) The fact that the propellant used is somewhat less prone to detonate than the propellant used in Lapua.

In other cases, a pneumatic supply system can well be an effective and justified safety measure. This example is intended to demonstrate that it is most important to account for the specific conditions of each single case. Such tailor-made solutions, however, are only possible if a systematic and strictly quantitative approach is used.

The quantification in the various steps of a risk analysis still can present problems. Since the availability of statistical data is sometimes limited, data have to be supplemented by quantitative professional judgement. The explicit and systematic methods of risk analysis clearly show where more precise data have to be collected. However, even if subjective judgement is applied, the classical decision theory shows that in complex problems, decisions based on a combination of facts and quantitative judgement are always superior to purely intuitive solutions.

This example shall demonstrate that the most economic combination of safety measures can only be found if the "safety goals" are set explicitly and quantitatively. Such general safety goals make it possible to assess and compare the safety of other facilities on the same basis.

References:

1. "Report of the Explosion Accident at Lapua Cartridge Factory in Finland, 13th April, 1976"
   Ministry of Defence, Inspector of Explosives, Helsinki

2. "Some Principles for a Quantitative Approach to Safety Problems in Explosive Storage and Manufacturing in Switzerland"
   Paper presented to 17th DoD Explosives Safety Seminar in Denver, Colorado, USA, 1976

3. "How much Should we be Willing to Pay for Explosives Safety"
   Paper presented to 18th DoD Explosives Safety Seminar in San Antonio, Texas, USA, 1978

4. "Richtlinien für die Sicherheitsbeurteilung beim Verkehr mit Munition und Explosivstoffen in den Rüstungsbetrieben"
   (SER 81), Gruppe für Rüstungsdienste, Berne, Switzerland

s

5. "Sicherheitsmässige Beurteilung der geplanten pneumatischen Pulverzuführung"
   Gruppe für Rüstungsdienste, Berne, Switzerland
   Performed by Ernst Basler & Partners, Zürich, Switzerland

MANUAL PROPELLANT SUPPLY SYSTEM

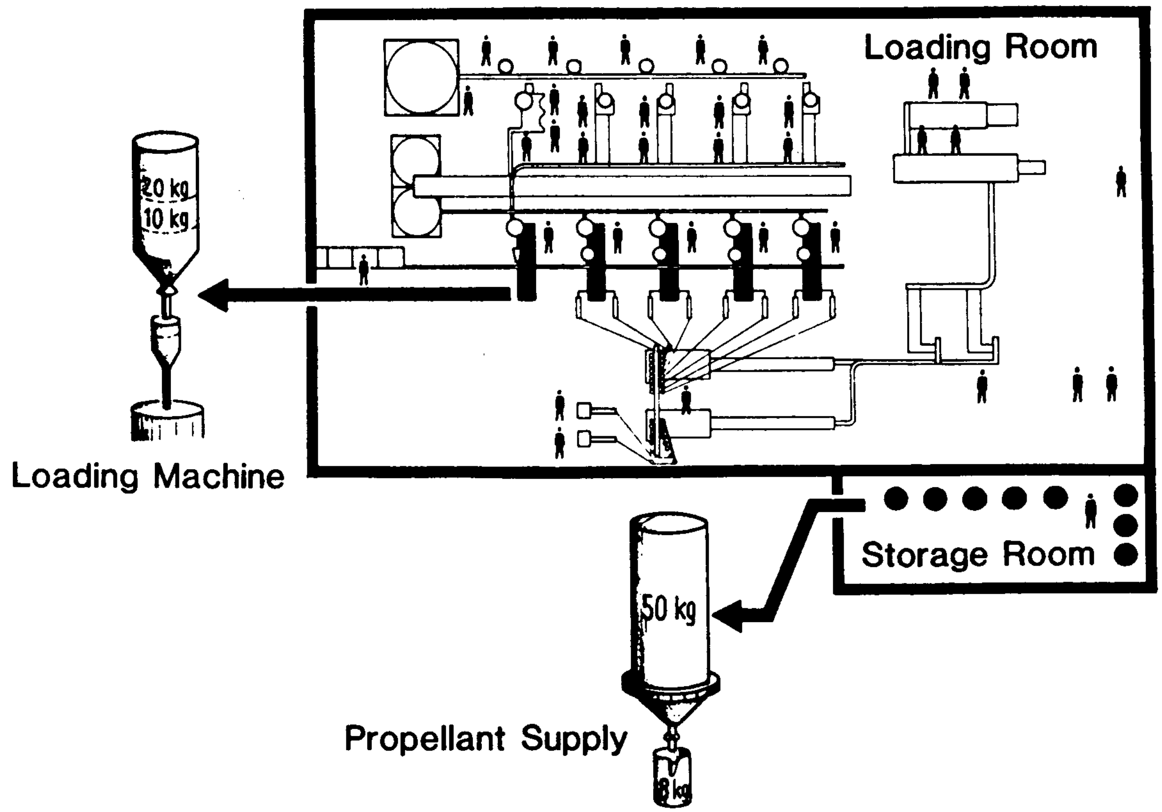


Figure 1

PNEUMATIC PROPELLANT SUPPLY SYSTEM

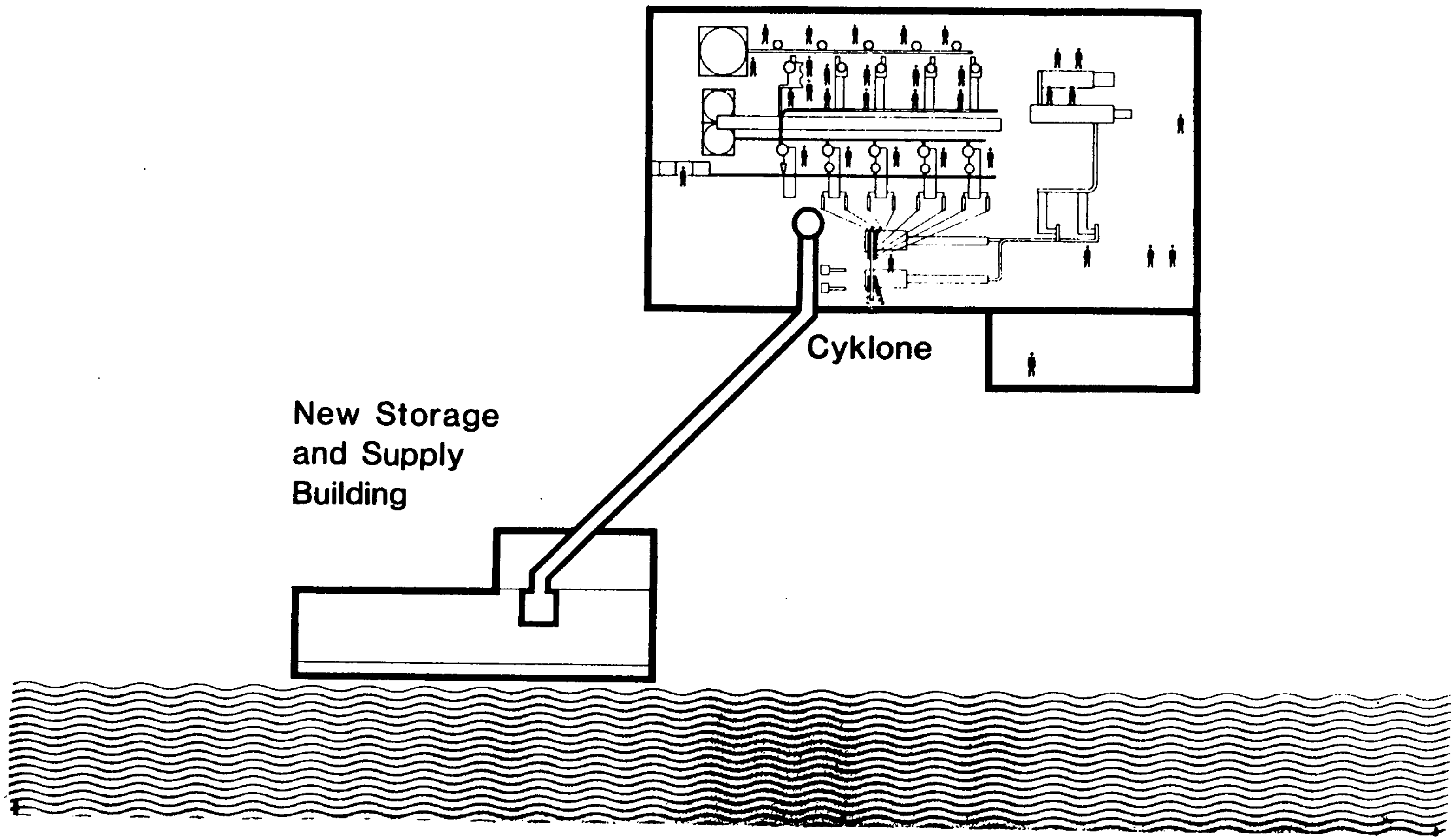


Figure 2

THREE BASIC QUESTIONS

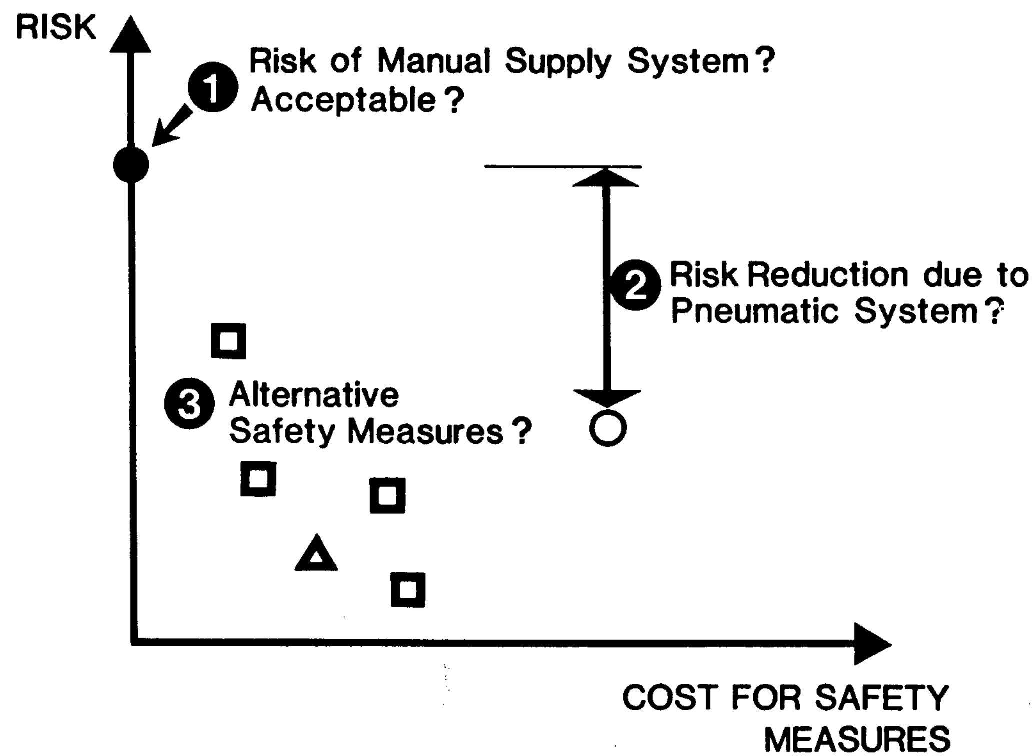
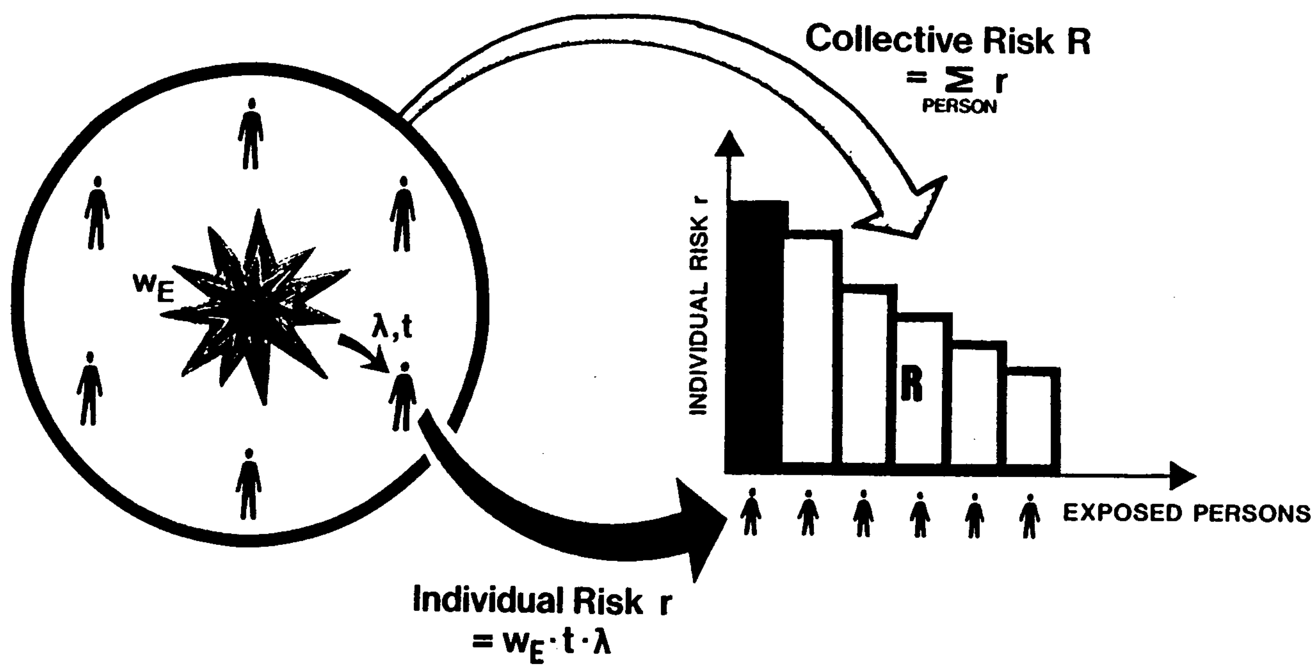


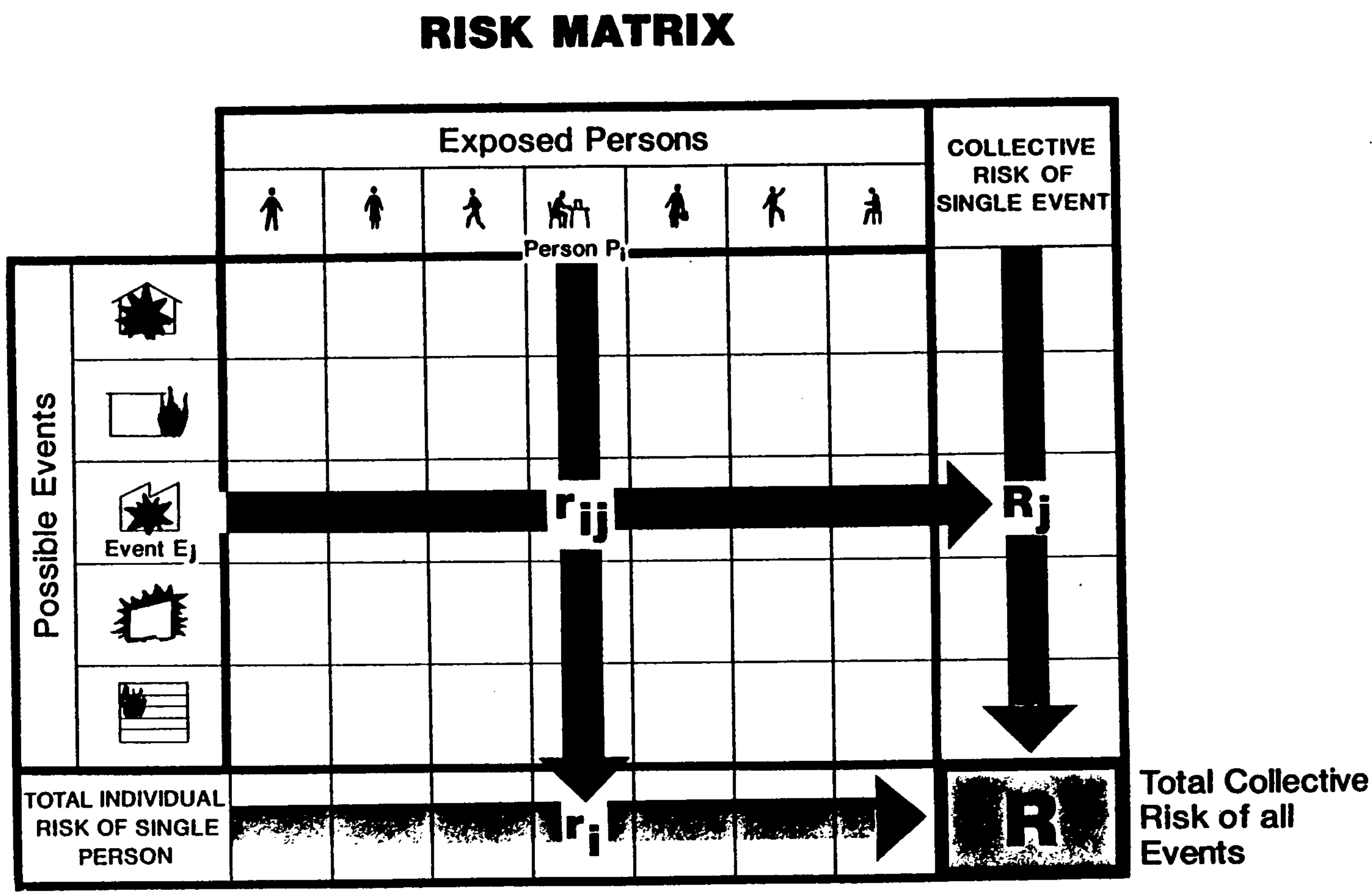
Figure 3

INDIVIDUAL AND COLLECTIVE RISKS



w_E = Probability of Event
t = Probability of Presence
λ = Probability of Fatal Injury

Figure 4



RISK MATRIX
Exposed Persons
COLLECTIVE RISK OF SINGLE EVENT
Person P_i
Possible Events
Event E_j
r_{ij}
R_j
TOTAL INDIVIDUAL RISK OF SINGLE PERSON
r_i
R
Total Collective Risk of all Events

Figure 5

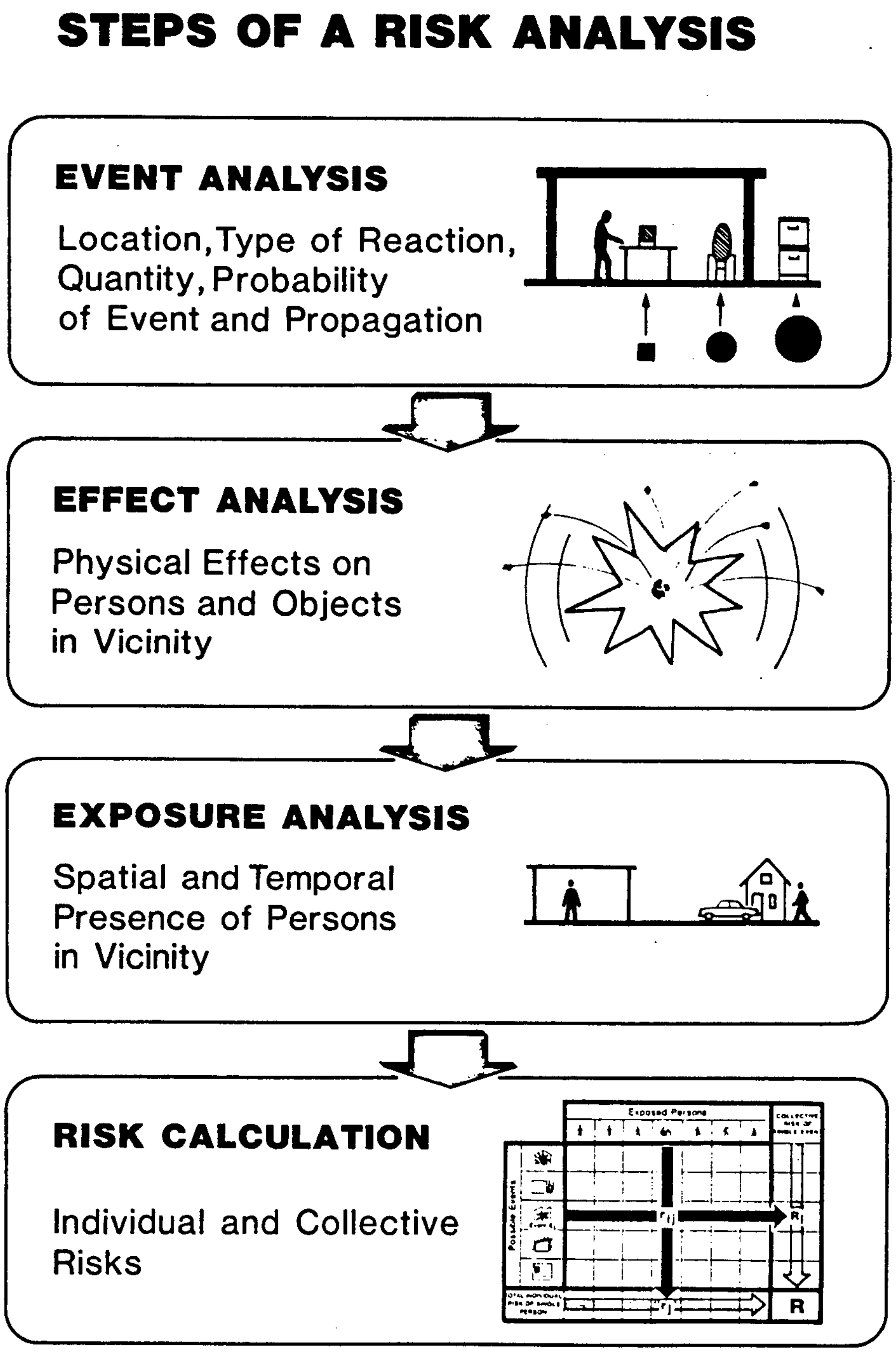

STEPS OF A RISK ANALYSIS
EVENT ANALYSIS
Location,Type of Reaction, Quantity, Probability of Event and Propagation
EFFECT ANALYSIS
Physical Effects on Persons and Objects in Vicinity
EXPOSURE ANALYSIS
Spatial and Temporal Presence of Persons in Vicinity
RISK CALCULATION
Individual and Collective Risks
Exposed Persons
R

Figure 6

RISK CRITERIA

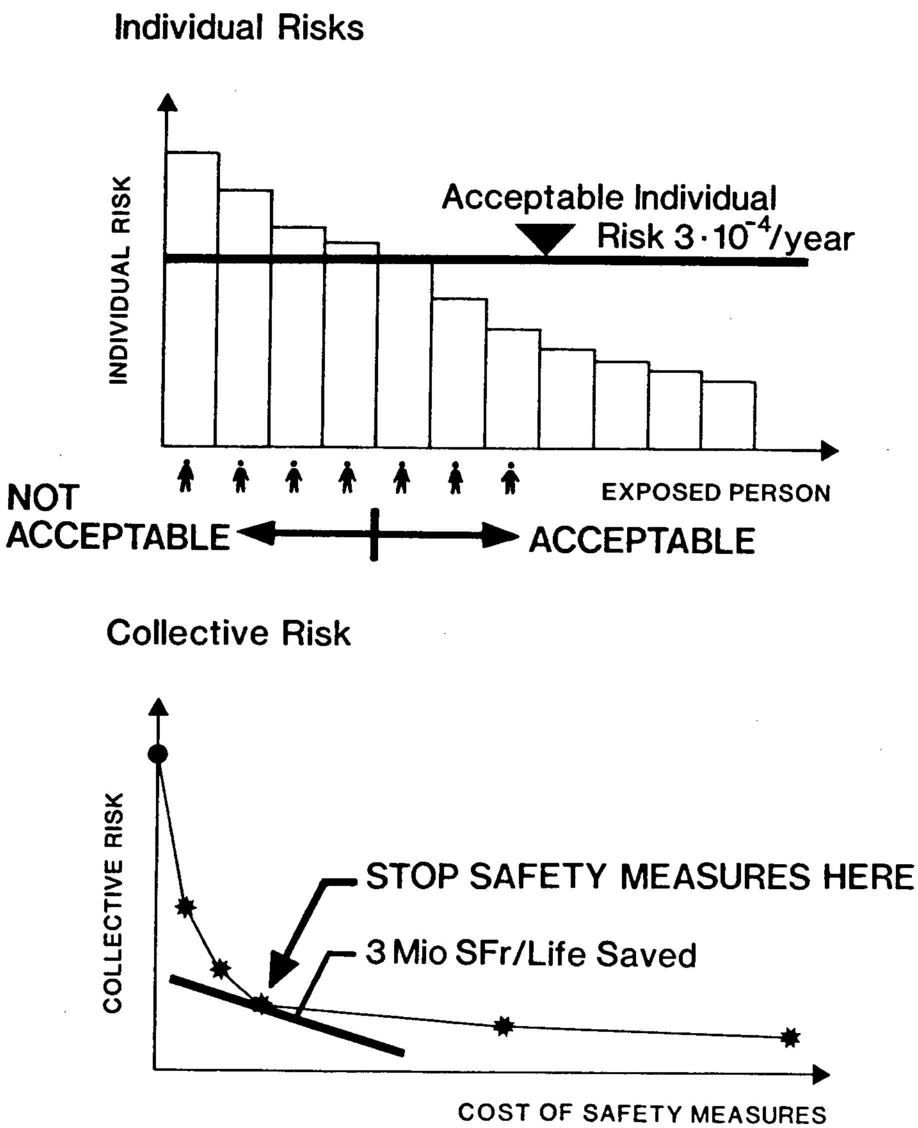
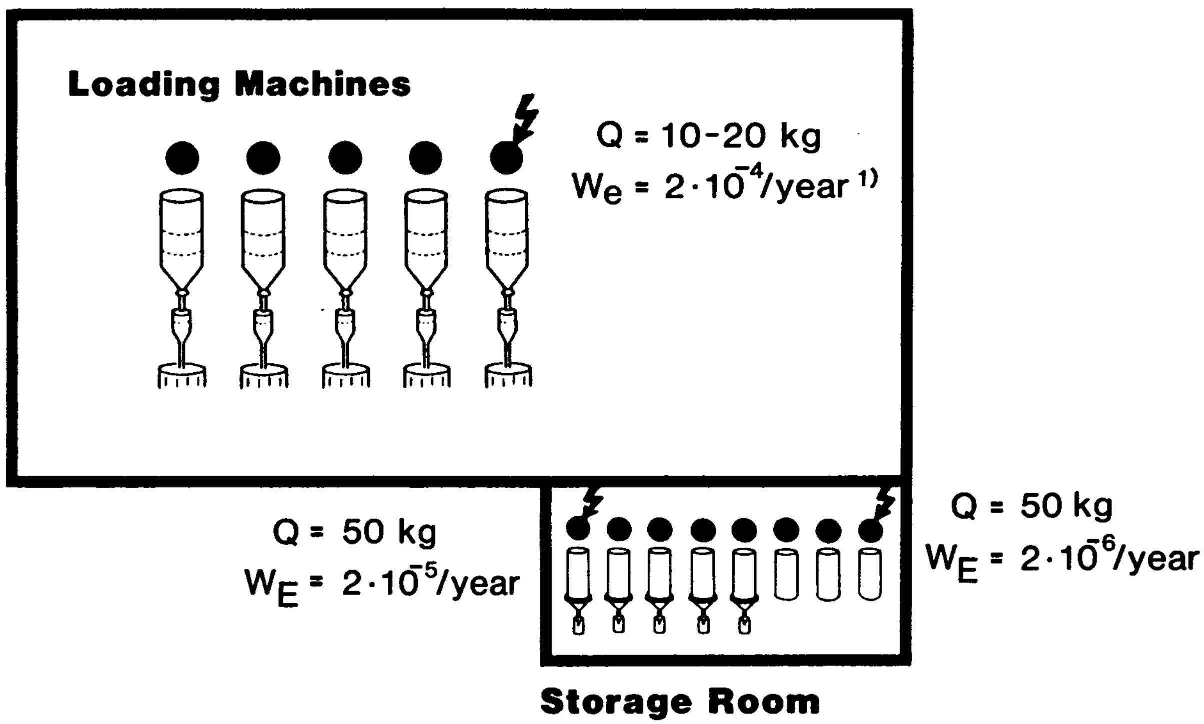


Figure 7

EVENT ANALYSIS

Location and Basic Probabilities (Example for Manual Supply)



[1] 1 year = 8760 hours of operation

Figure 8

EVENT ANALYSIS

Transition and Propagation Probabilities (Example for Manual Supply)

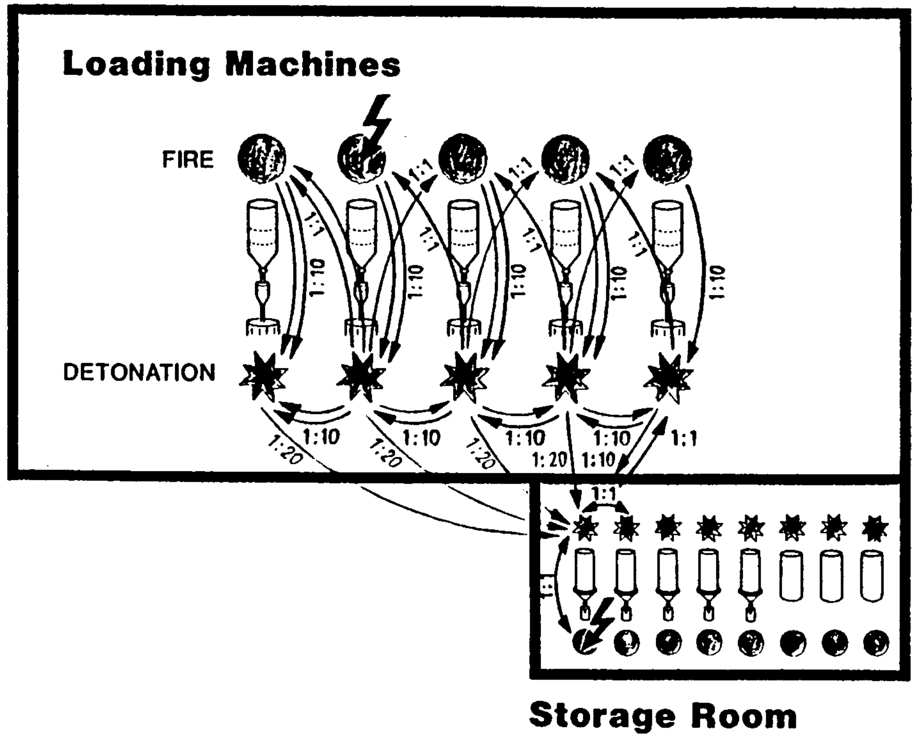


Figure 9

EFFECT ANALYSIS

Example of Lethality Isolines for Persons Exposed to Detonation of 800 kg of Propellant

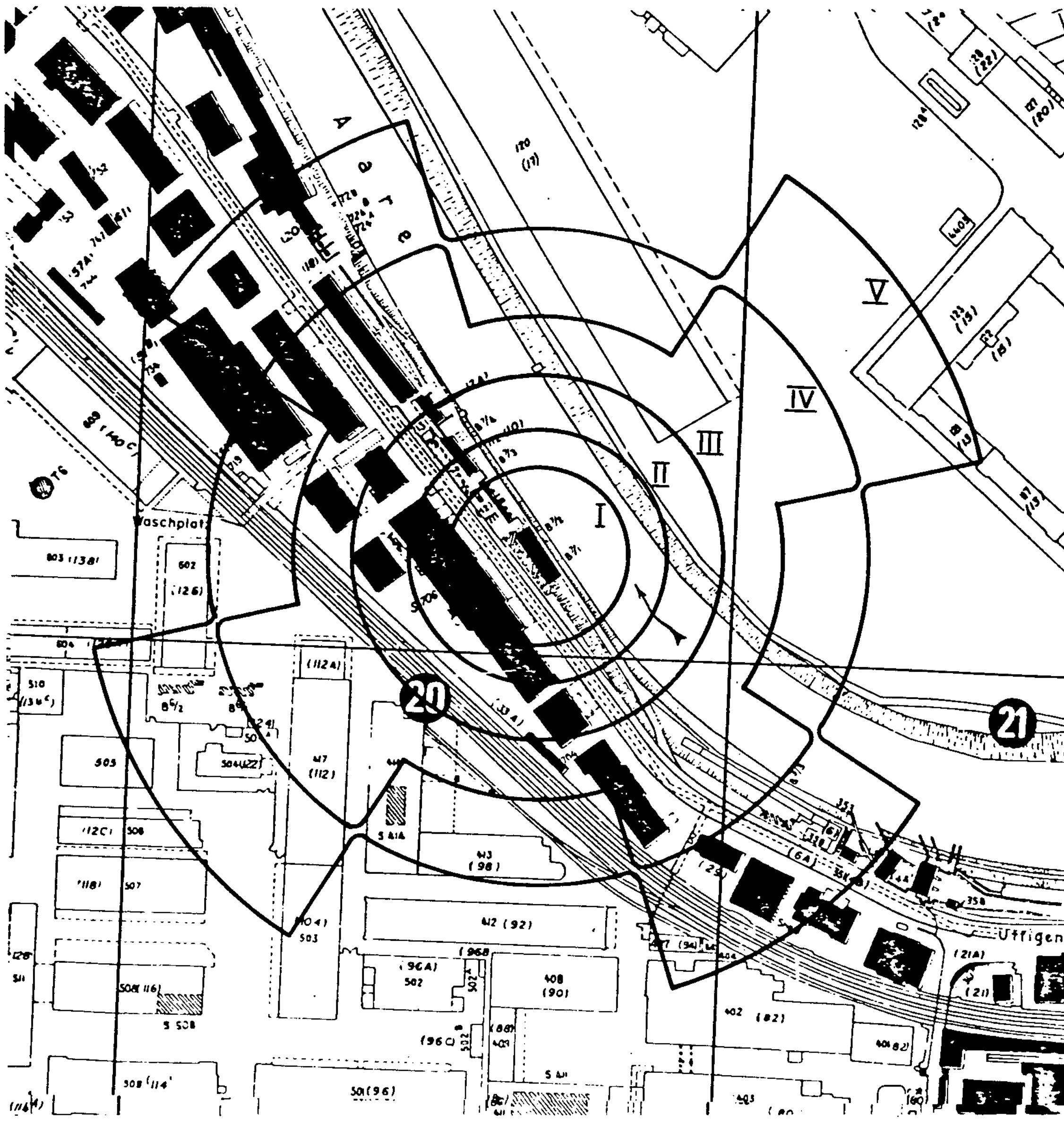


Figure 10

RESULTS OF RISK ANALYSIS

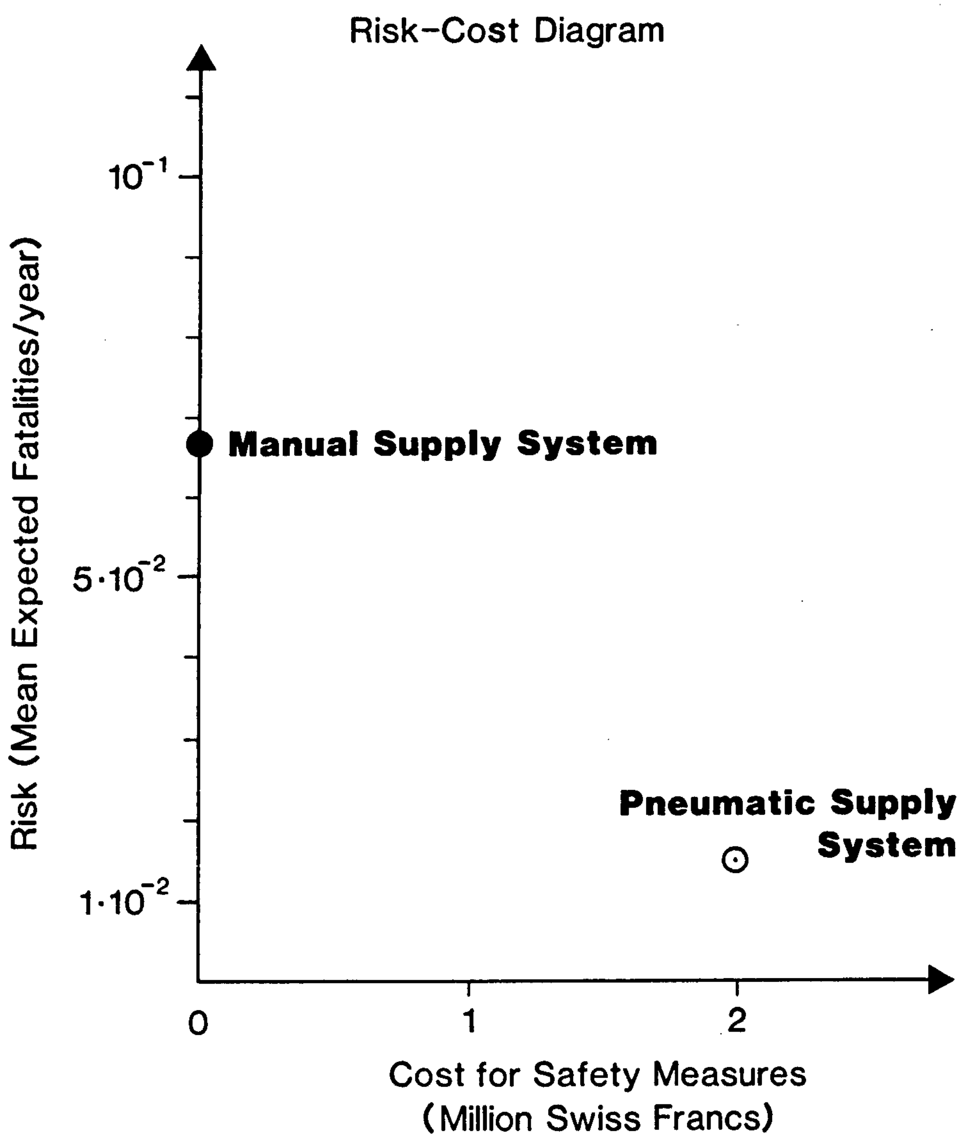


Figure 11

RESULTS OF RISK ANALYSIS

Contributing Factors to Risk
of Manual Supply System

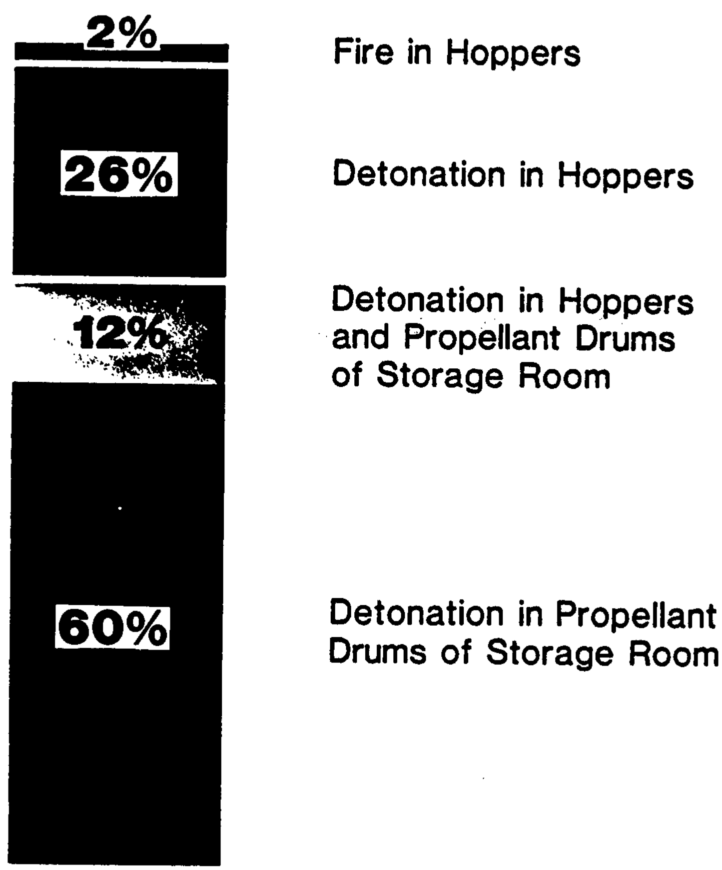


Figure 12

RESULTS OF RISK ANALYSIS

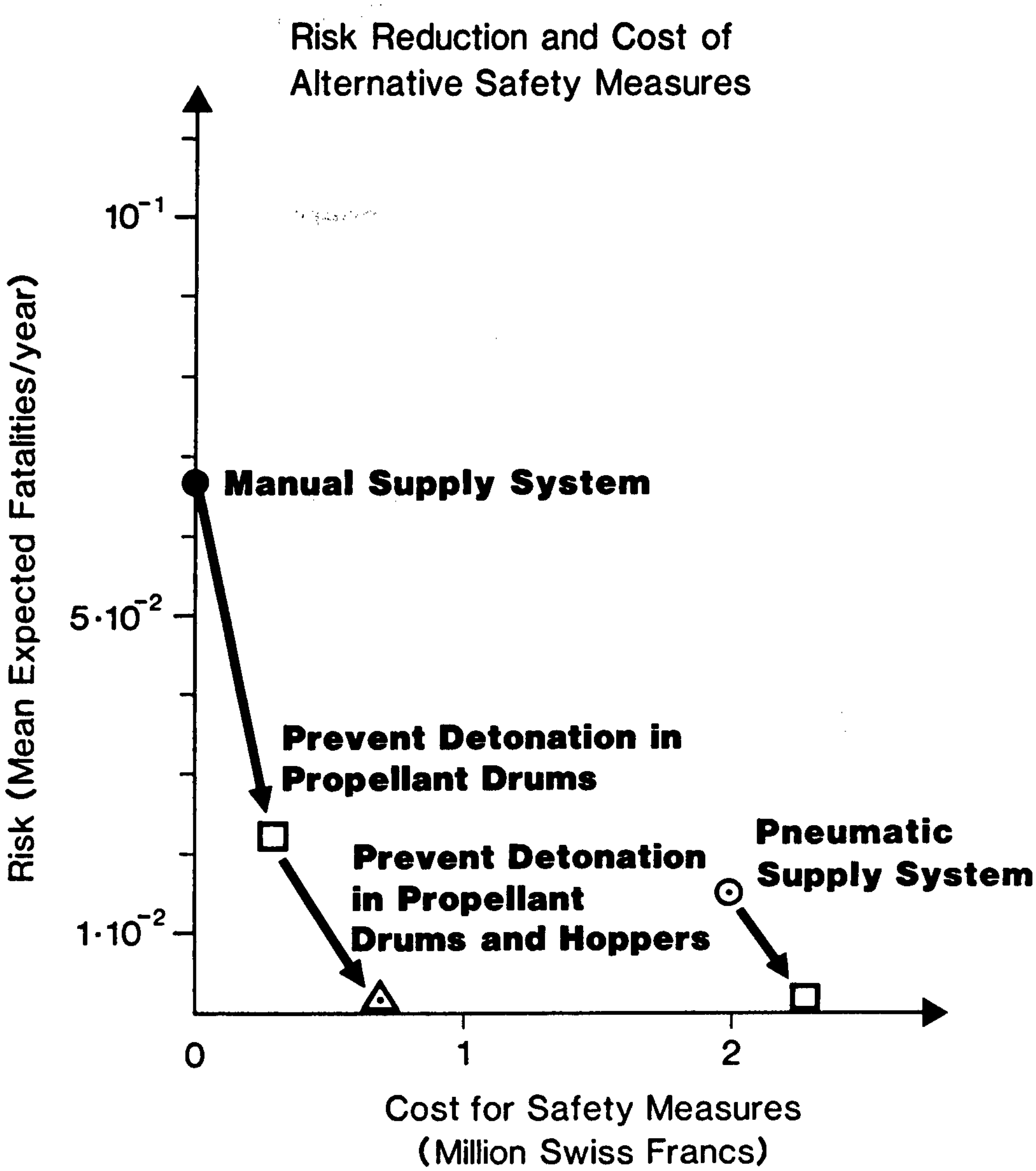


Figure 13

DEVELOPMENT OF A PRELIMINARY HAZARD ANALYSIS (PHA)

OF

BINARY REACTOR

BY

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Aberdeen Proving Ground, MD 21010-5423

LITERATURE CITED

1. Military Standard 882B, System Safety Program Requirements, 30 March 1984.

PREFACE

This report was developed in support of the Chemical Research and Development Center (CRDC) Safety Office. Although it addresses many of the health and safety aspects of a safety program during the evaluation process of a Standing Operating Procedure (SOP), this publication cannot be all encompassing. Supplementary and/or specific guidance is contained in the selected references.

1. INTRODUCTION

The Chemical Research and Development Center (CRDC) mission is to conduct research and to provide life cycle engineering for chemical weapons, and chemical and biological defense. For CRDC to meet its mission requirements, operations must be conducted utilizing chemical agents. One means used by the Safety Office to ensure compliance with safety and operational requirements is to require a Standing Operating Procedure (SOP) for all hazardous operations. During the SOP review process, a preliminary hazard analysis (PHA) is developed for new operations involving chemical agents.

The purpose of this report is to define the requirements for a PHA, the methodology used to develop a PHA, and to show the applicability of a PHA for use with chemical agent operations.

The operation being evaluated by PHA in this report is the binary reactor. The binary reactor is a pressure vessel specifically designed to simulate a munitions formation of binary lethal agents under various test conditions.

2. METHODOLOGY

A PHA is a working document developed during the planning stages of the operation. It is used as a comprehensive safety evaluation of the operation. The PHA identifies hazardous conditions, causes of these situations, hazard severity, hazard probability, and the recommended corrective actions to be taken to alleviate the hazardous conditions.

A PHA should be developed for new operations involving chemical surety materiels. A PHA is developed in the following sequence. The rough draft of the SOP is received from the operating division for review. During the review process, a PHA is developed for the SOP. The information used in the PHA is derived from the rough draft SOP, interviews with the operators, and pre-operational runs with simulants. During the review process, hazardous conditions are identified and corrective actions are developed to eliminate or control the hazard. The corrective actions from the PHA are provided to the operating division and incorporated into the SOP. The SOP is then submitted for final approval.

Various formats are used when developing a PHA, the more commonly used are columnar, narrative or logical diagram. The format currently being used for the development of PHA's by the author is the columnar format for the procedural analysis with a narrative introduction. The introduction has a section on the hazard severity and hazard probability tables being used from MIL-STD-882B, the statement of work, a description of the decontamination solutions require for the operation, the chemicals being used in the operation and chemical surety materiel formed, miscellaneous hazards, and the personal protective clothing and equipment required for the operation.

The columnar portion of the PHA is divided into seven sections. The sections include System Event(s) Phase, Hazard Description, Effect on System, Risk Assessment, Recommended Action, Effect of Recommended Action on Risk Assessment, and Remarks.

The System Event(s) Phase section is used as a identifier of the hazard described within the SOP. Each paragraph in a SOP is numbered and that number is placed in this column for ease of locating the hazard in the SOP.

The Hazard Description Section identifies the hazardous situation or critical safety concern within that specific step of the operation.

The Effect on System section describes the possible injury to the operators due to the hazard, the damage to the equipment, and the possibility of chemical surety materiel being released from containment.

The Risk Assessment section utilizies the symbols from the tables in MIL-STD-882B for the coding of hazard severity and hazard probability for a given hazardous situation.

The "Recommended Actions" section contains corrective actions formulated to reduce or eliminate the hazardous situation and/or the associated risk with a specific step of an operation. In some instances there are several alternative recommended actions which may be employed to alleviate a hazardous situation.

The "Effect of Recommended Action(s)" on the Risk Assessment section evaluates the recommended action to be employed for a given hazardous situation and reassigns a new risk assessment code to the specific step of the operation.

The Remarks section is used to list references and other significant comments.

Each section of the columnar format is used for every identified hazardous situation and the recommended action is incorporated into the SOP prior to final approval from the Safety Office.

3. PROCEDURAL

The operation being evaluated by this report is the binary reactor. The SOP for this operation is entitled "Binary Lethal Agent Reaction Studies". The SOP contains sections which list the materials and equipment being used, hazards involved with the operation, specific safety requirements, operational procedures, and emergency procedures. The PHA evaluates these procedural sections of the SOP. Appendix A is a portion of the SOP submitted to the CRDC Safety Office for review.

4. Evaluation

The completed PHA is attached as Appendix B and the major findings of that document are as follows:

Hazard: Overpressurization of the binary reactor during operation.

Corrective Action: To equip the binary reactor with both a manual and an automatic relief valve. The automatic relief valve is preset at 90 psi and the operator actuates the manual relief valve when the internal pressure within the binary reactor exceeds 120 psi.

Hazard: Pressure builds up within the binary reactor.

Corrective Action: Have the binary reactor hydrostatically pressure tested prior to use. The binary reactor will be tested for pressures in excess of the safety relief valves and the expected pressures to be produced by the reaction.

Hazard: The ventilation system fails during the operation.

Corrective Action: The operators will stop the operation as soon as possible. The individuals within the laboratory will don protective mask. The operators will containerize any open agent and then all personnel will evacuate the laboratory.

Hazard: Aluminum foil burst disk not installed properly or is leaking during the filling of the second component of the binary reactor.

Corrective Action: During the filling of the second component of the binary reactor, monitor the temperature of the first component on the recorder readout. If the thermal readout indicates leakage (increase in temperature), stop the filling operation, let the reacted material cool and then initiate cleanup procedures.

Hazard: Flammable solutions within the glovebox when electrically functioning the sampling and injection solenoids.

Corrective Action: Remove all flammable solutions from the glovebox prior to electrically functioning of the sampling and injection solenoids.

5. Conclusions

A PHA was very useful during the review process of SOP entitled "Binary Lethal Agent Reaction Studies". Several hazards were identified and the safeguards which were developed were placed into the SOP. These safeguards will enable the operator to conduct the operation of the binary reactor in a safer manner. It is felt by the author that a PHA should be developed for all hazardous operations.

APPENDIX A

Appendix A
will be furnished upon request.

Appendix B

This section of the report presents the results of the PHA which was developed for the SOP entitled "Binary Lethal Agent Reaction Studies" at Edgewood Area, Aberdeen Proving Ground.

a. Introduction:

The PHA identifies the hazards, possible causes, and formulates the risk assessment for each identified operational phase. Recommended actions to eliminate or control the identified hazards and to develop safety criteria for the operation.

2. Risk Assessment Tables:

ATTACHED

3. Statement of Work:

Conduct laboratory binary lethal agent reactions to study their formation in support of various binary agent munition programs. Several combinations of agent intermediates and catalysis will be mixed in a hastelloy reactor to determine the approximate agent reaction times, maximum temperatures, maximum pressures, purity of timed samples under controlled conditions. The data will be recorded for support of engineering and designing binary munitions.

4 Decontamination Solution:

There must be a readily available supply of an appropriate decontamination solution as well as adequate dispensing equipment. Personnel involved with the operation be properly trained in use of the decontamination solution and the dispensing equipment. Decontamination crews must have access to personnel protective clothing and equipment, and be trained in their use.

The following decontamination solutions are required dependent on the chemical agent being generated.

a. STB and HTH. US Army super tropical bleach (STB) is solid calcium hypochlorite stabilized with calcium oxide for storage in the tropics, and HTH is commercially available High Test Hypochlorite. HTH has a higher available chlorine content. The terms STB and HTH are interchangeable for use in this paragraph. Both STB and HTH are bleaches, strong oxidizers, and when the neat (solid) bleach is mixed with oxidizable materials (i.e., HD, alcohols), flames can be produced. STB and HTH are to be used as a 40/60 slurry (40 parts bleach stirred into 60 parts water). Bleach slurry is effective due to its base content and its oxidizing properties.

b. Household Bleach. Commercial chlorine household liquid bleach is a five percent to 5.25 percent sodium hypochlorite solution in water, sold as "Clorox", "Purex", and other trade names, these are also effective due to their basicity and oxidizing properties.

c. Sodium Hydroxide. Also known as caustic soda, lye. Sodium hydroxide is normally used as a five percent and a 10 percent solution in water (aqueous), or in a 50/50 alcohol-water solution (alcoholic). The alcohol could be methanol, ethanol, isopropanol, or methylcellosolve depending on availability, intended use, and flash point (fire safety) concerns. CAUTION: Mixtures of alcoholic caustic and chlorinated solvents slowly degas, therefore, those mixtures must not be put into a closed container.

d. Water. Water reacts with some of the chemical agents rapidly, but with others it reacts very slowly to not at all. Water is not in itself considered a good general decontaminant because of lack of reactivity and solubility. However, soap and water, and/or a safety shower, are suggested for the first step in personnel decontamination. A soap and water wash of hands and arms is required after handling toxic materials. In these cases, the toxic material is physically removed from the skin by a combination of mechanical and solvent action.

5. Chemicals being generated or being used during the operation.

a. Nerve gas

1. The principal hazard from nerve agents is agent vapor inhalation with sonsequent absorption through the respiratory tract, although all the agents may be absorbed on contact through the intact skin, through eyes, and through gastrointestinal tract, if ingested. All are highly toxic and quick acting. At ambient temperatures, GB is a liquid with moderate vapor pressure. When dispersed as large droplets, GB is moderately persistent; it

is nonpersistent when dispersed as a cloud of very fine particles. VX and GD are persistent and are primarily a liquid hazard. Inadvertent skin contact is the principal hazard from these agents. Percautaneous exposure to either liquid or vapor may be fatal, although the dosage by the percautaneous route is much higher than the respiratory route.

2. Some agents, GD in particular, are mixed with a thickener resulting in a solution or gel resembling rubber cement or glue. Swabs, pipettes, or hypodermic needles may trail stringers or filaments of solution. This effect is most pronounced in solutions having viscosities in the range of 1000-3000 centistrokes. These stringers may be distributed by air streams resulting in contamination at the working area. One technique for dealing with this hazard is to hold a towel downstream from swab, pipette, or hypodermic needle and to wipe the tip of the device before proceeding with the operation.

a. Methyl Phosphonic Difluoride(DF) is a strong acid which reacts violently with water; exposure will cause burns/rash. Prolonged exposure to vapors causes damage to the nervous membranes and may cause bronchitis, hazard to the eyes.

b. Alcohol/Amines are a non-hazardous component of the reaction, slight flame hazard, skin and eye irritant.

c. QL can irritate the mucous membranes and cause headaches.

d. Diisopropylcarbodiimide (DICDI) causes severe erythema on contact with the skin and will cause corneal damage upon contact with the eye. DICDI is a suspected mutagen or carcinogen due to its chemical structure.

6. Electrical Equipment. Electrical equipement shall be free from hazards that are likely to cause death or serious physical harm to employees. Compliance with OSHA 1910.303, 304, 305 and the National Electrical Code is mandatory. All flammable liquids will be removed from the glove box prior to the starting of the operation.

7. Personal Protective Clothing and Equipement (PPC&E). Personnal protective clothing and equipment to be worn during the operation are listed in Section 6d of the SOP. The hazards likely to cause death or serious physical harm to employees when wearing PPC&E are not suiting up properly, wearing improper or damaged protective clothing, and tearing protective clothing while conducting the operation.

PRELIMINARY HAZARD ANALYSIS

System Binary Lethal Agent Reaction Studies

Subsystem ______

Component ______

Prepared by: ______

Issue Date: 5 July 83

Rev ______ Sht 1 of 8

System Event(s) Phase	Hazard Description	Effect on System	Risk Assessment Sev.	Risk Assessment Prob.	Recommended Action	Effect of Recommended Action	Remarks
(1) (7a 5)	The reuse of non-standard glove-box gloves for an operation.	Possible skin contact with agent through a hole/tear in the glove or by agent which has penetrated through the glove.	I	B	Replace non-standard glove-box gloves prior to every operation. In the event of an actual or suspected liquid agent contamination, the gloves will be decon-taminated and removed as soon as feasible. All gloves will be leak tested prior to use.	III C	IAW DARCOM R 385-102, para 4-2 (g)(2)
(2) (7a 6) (7a 13)	Handling binary intermediate chemicals with-out gloves or approved gloves.	Possible skin irritation from amines and QL. Possible erythema from DICDI and burns/rash from DF.	II	B	Use protective rubber gloves when handling amines and QL. The operator will wear protective rubber gloves, rubber apron, and chemical goggles or face-shield when handling DICDI and DF.	III D	

PRELIMINARY HAZARD ANALYSIS

System Binary Lethal Agent Reaction Studies

Subsystem: ______

Component: ______

Prepared by: ______

Issue Date: ______

Rev ______ Sht 2 of 8

System Event(s) Phase	Hazard Description	Effect on System	Risk Assessment		Recommended Action	Effect of Recommended Action	Remarks
			Sev.	Prob.			
(1) (7a 5)	Wearing non-standard gloves beyond specified time limit.	Possible loss of protection from non-standard gloves and potential exposure to operators by agent penetration of gloves.	II	B	When using non-standard gloves, use a timing device with an audible alarm to prevent usage of gloves past the specified time limit.	IV D	IAW CSL SOP 385-1 para 4-7 (b) (2)
(4) (7a 10)	Flammable solutions within the glovebox when electrically functioning the sampling and injection solenoids.	Possible ignition of flammable solution.	I	B	Remove all flammable solutions from glovebox prior to electrically functioning of the sampling and injection solenoids.	IV D	

PRELIMINARY HAZARD ANALYSIS

System Binary Lethal Agent Reaction Studies

Subsystem ____________

Component ____________

Prepared by: ____________

Issue Date: ____________

Rev ________ Sht 3 of 8

System Event(s) Phase	Hazard Description	Effect on System	Risk Assessment Sev.	Risk Assessment Prob.	Recommended Action	Effect of Recommended Action	Remarks
(5) (7a 14)	Aluminum foil burst disk not installed properly or is leaking.	Possible premature formation of agent.	II	B	During filling of the second component, monitor the temperature of the first component on the recorder readout. If thermal readout indicates leakage (increase in temperature), stop filling operation, let reacted material cool and then initiate clean-up procedures.	III C	
(6) (7a 18)	Operator keeping hands inside of the glovebox during the mixing of the material within the binary reactor.	Possible pressure build-up during mixing process and reactor vents.	II	B	Operator will remove hands from the glovebox during the production of agents.	III C	

PRELIMINARY HAZARD ANALYSIS

System Binary Lethal Agent Reaction Studies

Subsystem ______

Component ______

Prepared by: ______

Issue Date: ______

Rev ______ Sht 4 of 8

System Event(s) Phase	Hazard Description	Effect on System	Risk Assessment Sev.	Risk Assessment Prob.	Recommended Action	Effect of Recommended Action	Remarks
(7) (7a 20)	The automatic relief valve (spring loaded) does not actuate at the preset pressure.	Possible pressure build-up and possible rupture of reactor and operator injury.	II	B	a) If automatic relief valve (spring valve) does not actuate and pressure builds within the binary reactor, the operator will actuate the manual relief valve to vent the binary reactor, until the internal pressure is 0 psi. b) Change automatic relief valve (spring valve) to a simpler type of a relief valve (i.e, burst disk).	II C	

PRELIMINARY HAZARD ANALYSIS

System: Binary Lethal Agent Reaction Studies
Subsystem:
Component:

Prepared by:
Issue Date:
Rev ____ Sht 5 of 8

System Event(s) Phase	Hazard Description	Effect on System	Risk Assessment Sev.	Risk Assessment Prob.	Recommended Action	Effect of Recommended Action	Remarks
(8) (7a 23)	Removal of sample bottles from the glovebox	Possible agent release from contaminated bottles.	II	B	Operator cleans contaminated gloves with appropriate decontamination solution. Wipe the bottles with decontamination solution and then test bottles with M8 paper. Repeat test until no agent is indicated. Seal sample bottles with parafilm and pass bottles through the passbox to the hood. Bottles will be placed with a can and sealed and then placed within another can and then sealed. Properly label outside of storage containers.	III D	

PRELIMINARY HAZARD ANALYSIS

System Binary Lethal Agent Reaction Studies

Subsystem ______

Component ______

Prepared by: ______

Issue Date: ______

Rev ______ Sht 6 of 8

System Event(s) Phase	Hazard Description	Effect on System	Risk Assessment Sev.	Risk Assessment Prob.	Recommended Action	Effect of Recommended Action	Remarks
(9) (7a 26)	Clean-up Operation of binary reactor and glovebox.	Possible agent exposure to personnel.	II	C	All excess agent will be containerized in a bottle. The reactor and components will be washed down with acetone and the washings will be poured in the same bottle that the excess agent was placed into. The bottle will be cleaned and sealed with parafilm and passed to the passbox. Paper waste refuse and solid waste will be placed into a solid waste container. The lower portion of the glovebox will be washed down with a caustic (bleach) acetone mixture (only the lower surface of the glovebox). Decontaminate and remove gloves and place in solid waste can, pour removing decontamination solution over solid waste.	III D	

PRELIMINARY HAZARD ANALYSIS

System Binary Lethal Agent Reaction Studies

Subsystem ______

Component ______

Prepared by: ______

Issue Date: ______

Rev ______ Sht 7 of 8

System Event(s) Phase	Hazard Description	Effect on System	Risk Assessment Sev.	Risk Assessment Prob.	Recommended Action	Effect of Recommended Action	Remarks
(10) (7a 29)	Operators leave work area without washing hands.	Possible that operators' hands are contaminated with intermediate chemicals or agent.	III	C	IAW good laboratory practices operators should was hands and arms with soapy water prior to leaving the work area.	IV D	
(11)	Ventilation failure during the operation.	Glovebox losses negative pressure and hood drops below 150 ± 30 lfpm. Possible agent migration from ventilated containment.	II	B	Stop operation as soon as possible, individuals in laboratory don mask, containerize any open agent and evacuate laboratory.	III C	

PRELIMINARY HAZARD ANALYSIS

System Binary Lethal Agent Reaction Solution

Subsystem ______

Component ______

Prepared by: ______

Issue Date: ______

Rev ______ Sht 8 of 8

System Event(s) Phase	Hazard Description	Effect on System	Risk Assessment Sev.	Risk Assessment Prob.	Recommended Action	Effect of Recommended Action	Remarks
(12)	Glovebox leaks material after reactor vents contents.	Possible exposure to unprotected personnel.	II	B	Operators mask and help in the evacuation of the building.	III C	
(13)	Pressure builds up within the binary reactor during the operation.	Reactor ruptures. Possible release of agent. Possible damage to glovebox and injury to operating personnel.	I	B	Have binary reactor hydrostatically pressure tested prior to use. Have reactor equipped with an automatic relief valve and a manual relief valve.	III C	

TOTAL SYSTEM HAZARDS ANALYSIS FOR THE WESTERN AREA DEMILITARIZATION FACILITY

by

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ABSTRACT

The results of a hazards analysis of the Western Area Demilitarization Facility (WADF) at Hawthorne, Nevada are summarized. This paper contains an overview of the WADF systems, the hazards analysis methodology that was applied, a general discussion of the fault tree analysis results, and a compilation of the conclusions and recommendations for each area of the facility.

1. BACKGROUND

This paper summarizes a total system hazards analysis completed in 1982 for the Western Area Demilitarization Facility at Hawthorne, Nevada (Ref. 1, 2, 3, and 4). The Western Area Demilitarization Facility (WADF) was designed "to demilitarize obsolete, out-of-date, or unserviceable conventional ammunition items by safe, economical, and environmentally acceptable techniques" (ref. 5). The volume of such material that should be disposed of had been increasing significantly. Costs associated with storage (space, record keeping, and security) were increasing. Existing facilities were not easily adapted to handle the required production rates. Thus, there was a real need for such a facility.

The WADF system consists of the Off-Loading Dock, Driverless Tractor System, Preparation Building, Accumulator Building, Mechanical Removal Building, Large Cells, Washout/Steamout Building, Process Water Treatment Facility, Bulk Explosives Disposal Building, Refining Building, Flashing Chamber, and the Decontamination and Small Items Building. These were evaluated for hazards under three priorities. Priority 1 included the "wet systems" (Washout Steamout Building, Refining Building, Bulk Explosives Disposal Building, and the Process Water Treatment Plant). Priority 2 included the Preparation Building, the Mechanical Removal Building and the Large Cells. Priority 3 contained the Decontamination Building, the Large Items Flashing Chamber, the Driverless Tractor System, the Off-Loading Dock, and the Magazines.

The hazards analysis for the WADF was unique in two regards. First, the WADF was designed to demilitarize a tremendous variety of items. For each new type of items, special fixturing and procedural adjustments may be required. In a sense, WADF would provide the basic "tools" necessary to disassemble, cut open, remove propellants and explosives, decontaminate or dispose of the components, etc., but the specific procedures and fixtures might have to be adjusted for any new item to be demilitarized. In addition, the explosives and propellants in the items are generally old, may be contaminated or decomposed, and there may be compatibility problems between

the variety of materials that must be handled. These problems are not as severe a concern in more typical hazards analyses for, e.g. munitions manufacturing facilities, where the energetic materials, equipment/fixtures, and procedures are fixed.

Second, in conducting the hazards analysis, a Monte Carlo uncertainty analysis was used. The quantitative results (incident probability/year) were presented in terms of distributions of possible values rather than discreet values. The width of the distribution corresponds to the degree of uncertainty in the results and recommendations were structured with this degree of uncertainty in mind. We believe that this approach to developing recommendations and prioritizing the recommendations is a valuable improvement to hazards analysis.

2. BRIEF DESCRIPTION OF THE WESTERN AREA DEMILITARIZATION FACILITY

Off Loading Dock

Munitions items to be demilitarized enter the facility at the Off-Loading dock. The Off-Loading dock is a conventional earth covered unloading structure designed to handle delivery of energetic materials by train or truck. It consists primarily of two adjacent earth covered tubes for unloading trains, but also has unprotected docks next to the igloo type structure. Items are to be taken from the unloading dock to the preparation building via the driverless tractor system.

Driverless Tractor System

A driverless tractor (DLT) and ammunition cart system utilizing Prontow 601 vehicles has been installed at WADF. Two independent DLT control systems are present. One network (Region 1) moves tractors between the Off Loading Dock and the Preparation Building. The second network (Region 2) moves tractors between the Preparation Building and the various process buildings at the site. The battery powered tractors are guided by a low frequency signal transmitted from wires laid in slots cut in the concrete guide paths.

Preparation Building and Accumulator

Mechanical disassembly of items is to be performed in the Preparation Building in individual cell areas of the building. Processes include (1) pull apart of elements joined by crimping (e.g., removing the projectile from the cartridge case); (2) unscrewing the parts such as fuzes from projectiles, rocket motors from warheads, or fuzes and fin assemblies from mortar cartridges; (3) Removal of propellant from cartridges; and (4) Removal of primers from cartridge cases. The preparation Building cells are to handle gun type ammunition up to and including 6 inch. There are six work cells in the building. At the time of the analysis, cells 1 and 2 were not equipped. Cell 3 is for breakdown of 60 mm and 81 mm mortar cartridges. Two rounds at a time are placed on a holding fixture (steel plate shuttle) in front of the cell by an operator. At the proper time, the holding fixture is indexed into the cell through an access port. Once inside the cell, under the watchful

eyes of the control operator, the previously disassembled two rounds are picked up by the robot (manipulator) at the disassembly "lathe" and placed in the holding fixture. Next the robot picks up the complete rounds and brings them into clamping position at the "lathe". With the rounds held firmly, the chucks on either side of the cartridge unscrew the fuze on one end and the tail fin on the other end. The head and tail units are then automatically picked up and dropped into water-filled containers sitting next to the machine. The mortar body is carried by the manipulator to the shuttle conveyor to the corridor outside the cell.

Cells 4, 5, and 6 are dedicated to disassembly of gun ammunition. A conveyor from the corridor carries projectiles and cartridge cases into Cell 5. In Cell 5, a pull apart machine removes the projectile from the cartridge case on fixed munition. For plugged cartridge cases, when the shell and case are separate (separate gun ammunition) the pull apart machine is replaced by an end cut off machine which removes the end of the case by using a tube cutter type device. In that case, the projectile enters Cell 5 separately and goes directly to Cell 6. In Cell 6, an unscrewing machine, just like that in Cell 3, is used to remove fuzes and base fuzes.

The cartridge cases are moved by the robot from the tube cutting device into a horizontal position for the Removal of a wad prior to dumping of the propellant. The propellant is dumped from the cases onto a conductive rubber belt conveyor to be carried to the accumulator building. Then the cartridge case is shuttled into Cell 4 via a conveyor. In Cell 4, the cartridge case is automatically placed into a fixture to punch out the primer in its base. When the cartridge case is conveyed back into the corridor, the operator must manually remove the primer from the inside of the case.

As mentioned above, the propellant removed from the cartridge cases is conveyed to the Accumulator Building. At the accumulator, the material is routed from a storage hopper to a vibratory feeder conveyor and finally to a weigh hopper. The propellant is then metered into type III or MK IV containers for storage or sale.

Mechanical Removal Building

The mechanical Removal Building contains equipment used to expose the interior of conventional munition items and to provide access for explosive

removal processes. Also, in some cases on large munitions, the facility is used to provide vent/view holes in the item to facilitate inspection of the items prior to flashing them of residual materials in the flashing chamber. The operations include trepanning (hole cutting), sawing, shearing and punching of holes in munition items. Before entering the Mechanical Removal Building, some items are washed/steamed out leaving only small amounts (under ten pounds) of explosive in them, with acceptance determined by visual inspection, while other items are fully loaded.

Cell 1 houses equipment used for punching holes in, or shearing relatively small munition items (such as MK1 boosters or MK42 primers) containing appreciable amounts of energetic material. At the time of the analysis, primers longer than 8 inches were to be sheared into smaller pieces using an industrial-type hydraulically operated press.

Cell 2 contains a band saw for sawing items 25 inches in diameter or less. Initially, the MK4 depth charge noses were to be sawed off by the band saw to expose the explosive charge for easier removal.

Cell 3 holds trepanning (hole sawing) equipment to cut a series of 5 inch diameter vent/view holes simultaneously in large munition items. A special hole cutting machine, (equipped with a shuttling carriage, a deep bed filter and an aspirator) is applied in Cell 3 to produce the vent/view holes.

Large Cells

Three large cells (constructed with frangible walls and ceilings due to the hazardous operations performed on large munitions) are located adjacent to the Mechanical Removal Building. These house machines used in disassembly operations for large munitions items. Two of these cells were in use. Cell B is set up for cutting open MK 16 mines using a band saw. Cell C contains an unscrew machine for defuzing major caliber munition items. Cell A was empty and could be used for temporary storage of large munition items (within allowable charge weight limits).

Washout/Steamout Building

The Washout/Steamout Building consists of two towers separated by a support area containing a boiler room, steam room, and chemical laboratories. This facility is for wet Removal of explosives (i.e., by steam

and hydraulic processes). There are four categories of wet processes. First, for TNT or similar single phase meltable explosives, the material is melted by contact with a steam jet. It is drained from the item, de-watered, formed into dry flakes and packaged. This procedure is accomplished in the Steamout Building--North Tower. Second, for explosive D or other similar relatively soluble explosives, hot low pressure water is used to hydraulically wash out the material (by erosion and solution). The material is directed into a large transportable container for subsequent disposal at the Explosives Disposal Building. This operation is accomplished in the Washout Building--South Tower. For Composition A3 or similar press loaded explosives, a very high pressure (10,000 psi) water jet is used to break up the material by erosive action. The material is flushed out of the item, de-watered, and packaged. This operation is also accomplished in the South Tower.

Water Treatment Facility

The Process Water Treatment Facility sits adjacent to the Washout/Steamout Building. This is a fairly conventional system for water treatment. Feed is added to the clarifier with alum and polymer. The alum coagulates substances in the water. The polymer aids coagulation. The coagulation-flocculation begins with a rapid mix in the top and gentler mixing in the mid region. The agglomerated particles settle to the bottom and are removed with positive displacement pumps. The sludge from the bottom is only about 5 percent solids and is dewatered further in the sludge basins. The clarified water is then filtered. The effluent turbidity is monitored (from sand filters) and backwashing of the filters is initiated when the turbidity is too high. The sand filters remove any floc particles which have not settled from the chemical precipitation. The activated carbon columns remove organics. When the pressure gradient through the carbon columns becomes too high, either the media will be replaced or backwashing will be done. The pH of the water can be from 9 to 11; therefore, the H_2SO_4 is added and mixed with an in-line static mixer. The final pH should be in the range from 6-8.

Refining Building

The Refining Building is to be used for removal of melt-cast explosives from projectiles (small items, up to 7.2 in. depth charges). The exterior of the shell is exposed to pressurized superheated steam (dry thermal process

from the standpoint of the explosive). The items are positioned into a holding fixture designed to prevent the steam from entering the item and contacting the explosive inside. The items are then hoisted up and lowered into one of the autoclaves in the Refining Building. As the explosive melts, it is drained through the bottom of the autoclave unit into a steam jacketed holding tank. The liquid explosive is then fed into strands onto a stainless steel belt flaker. It cools and solidifies on the belt and is broken up into flakes at the exit end of the unit. The flaker unit is hooded to remove fumes and is protected by UV detectors used to trigger a water deluge. The flakes are metered by vibratory conveyor into a weigh unit and packaged for shipment or storage.

Bulk Explosives Disposal Building

Non-saleable energetic materials, such as explosive D and those double and triple base propellants that cannot be sold, are handled at the Bulk Explosives Disposal Building. Containers holding the material are conveyed into the slurry preparation area. The container contents are dumped into the feed hopper for the grinder. The feeder conveyor passes the material through a metal detector prior to discharge into the grinder. In the grinder, the material is ground, with water injection, into small pieces, and passed into the slurry tank. A slurry consisting of a 3:1 mixture of water to solids by mass (monitored by slurry density) is prepared in the slurry tank and then transferred to the feed tank in the adjacent cell of the building. The slurry is circulated in a loop at about 25 gpm between the feed tank and one of the two incinerator units outside of the building. It is bled off from the loop at about 7 gpm and injected into the oil fired rotating drum incineration unit. The primary incinerator section is a drum furnace rotating at 3 rpm. The combustion products then pass through an afterburner and exhaust stack.

Decontamination Building

This building contains three furnaces to decontaminate various items. First, a rotary type furnace is used for small arms ammunition containing lead. The items are placed into a rotating dumper and transferred into a conveyor which carries them to the furnace feeder. The lead items furnace is a conventional rotary type oil burner furnace. At the burner end, a narrow opening is left between the furnace and burner flanges for liquid lead (1) to

drip into a trough, (2) be carried to a water bath for cooling and (3) then be carried by conveyor to a hopper for subsequent removal by truck. The remaining refuse from the furnace is deposited onto a second conveyor and carried to a magnetic (ferrous/nonferrous) separator where it is directed into a "ferrous or nonferrous" semi-trailer positioned under the separator chute.

A second rotary furnace, the detonating items furnace, is quite similar to the lead items furnace. This incinerator does not have the spacing between flanges at the burner end since liquid lead is not to be removed. A separate conveyor is used to recycle some of the refuse to maintain the proper depth of material in the furnace body. Since this furnace must withstand items detonating within, the walls are stronger than the lead items furnace, and the center section is recessed to increase the residence time of the items near the center of the cylinder.

The fifth and sixth cells in the decontamination building house the tray type flashing furnace. Here, moderate sized items (previously cleaned out in other operations), will be decontaminated. Items are to be processed through a conventional heat-treating type furnace (fire brick walled) where they will be heated to a temperature at which any residual energetic material decomposes or burns. Typical items to be processed include rocket warheads (e.g. 2.75 in., 5.0 in.), depth charge warheads (e.g. MK4, MK5), and gun ammunition projectiles (e.g. 40mm through 5"/54).

Large Items Flashing Chamber

In the flashing chamber, smokeless powder is used to burn off residual explosive left in larger items from which the bulk of the explosive already has been removed. Decontamination of these items is required before the metal components can be sold as scrap. Deactivation and/or decontamination of contaminated items has been accomplished in the past primarily by exposing the material to a high temperature for a prolonged time such that the energetic material decomposes, burns, or detonates. This is accomplished by placing the items in a bonfire in a field burn. Short duration high temperature exposures have also been used in the past by placing smokeless powder in the internal cavities of the item and igniting the powder. There is some question as to whether flashing really will be effective in all cases due to the shortness of the high temperature pulse.At WADF flashing is to be accomplished inside a

At WADF flashing is to be accomplished inside a containment chamber designed to prevent products of combustion from escaping to the atmosphere. The combustion products are ducted underground to a regenerative heat exchanger (a mass of steel tubes) and to a bag house for pollution control.

Pneumatically driven mine cars are to be used to carry the contaminated items from the DLT (item receiving area) into the car preparation enclosure, where the smokeless powder is layed, and then into the flashing furnace. A narrow gage track loop routes the mine cars into the chamber and then back out to a cool off area. A massive door covers the chamber's entrance during a burn.

3. HAZARDS ANALYSIS METHODOLOGY USED

Each area of the WADF was evaluated using the following procedure:

a) Collect Available Information

b) Review Information/Learn System

c) Conduct an Informal Failure Modes and Effects Analysis (FMEA)*

d) Develop Fault Tree Logic Diagrams for System (FTA)

e) Quantify Fault Tree (derive scenario probabilities)

f) Interpret and Summarize the FTA Results

For the purposes of this study, the failure modes and effects analyses served to identify types of consequences and types of scenarios to be expected in different areas of the WADF. The FMEA's were used to learn the system and guide the development of the fault trees. Fault tree analysis was the primary methodology used to identify and quantify credible hazards at the facility. The FMEA and FTA approaches are well known and described in a vast store of literature on hazards analysis methodologies. A summary of these approaches is provided in references 1-4. In this paper only the more unique aspects of the FTA approach used will be discussed. These were concerned with consideration of uncertainties in the quantitative inputs (system scheduling data, part reliabilities, human error probabilities, and initiation probabilities).

IITRI has a fault tree analysis computer program for evaluating the fault tree logic diagrams. The first portion of the computer code uses a matrix approach known as the Boolean Indiated Cut Set (BIC) method to reduce the tree logic to a list of scenarios (cut sets) that "lead to" the undesired top event of the tree. These cut sets are the hazard scenarios that must be evaluated.

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* The term FMEA refers here to the general inductive logic tabular approach including a wide variety of specific formats such as fault hazards analysis (FHA), operating and support hazards analysis (O & SHA), etc.

Each basic event on the fault tree must be provided a probability of occurrence or a failure frequency (with associated downtime) for quantification of the tree. Four types of data must be compiled to quantify the trees:

1. System Scheduling Data
2. Part Reliabilities
3. Human Error Probabilities
4. Initiation Probabilities

Scheduling information was largely inferred from reference 5. Part reliability data has been compiled at IITRI during prior hazards and reliability analyses from numerous sources. The primary source of reliability data used, however, was a compilation of non-electronic parts data developed by the Reliability Analysis Center, an IITRI organization in Rome, New York (reference 6). Human error data has been compiled under a project conducted by IITRI for the Chicago Transit Authority (reference 7) and that was the primary source for human error probabilities used. For initiation probabilities, the primary source of data was from earlier hazards analyses for WADF presented in reference 5. Because of the nature of the demilitarization operation, a wide variety of energetic materials could be present at any plant location. Not all the possible materials were considered. Only the most sensitive material for which data was available was used for each stimulus type.

The criteria for safety adequacy for this analysis was given as: "The minimum acceptable level of risk for the operation and maintenance for the entire WADF complex and any subsystem is 97.5 percent probability with a 95 percent confidence level that a category 1 or 2* accident will not happen during 25 years of operation (40 hours per week)."

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* Hazard categories are defined as follows:

Category 1 - Catastrophic. May cause death or system loss. System loss shall be defined as damage which results in the loss of 25 percent or more production capability and requires 30 days or more to repair.

Category 2 - Critical. May cause severe injury, severe occupational illness or major system damage. Major system damage shall be defined as

This translates to specifying that the hazard incident probability per year for the entire facility is less than or equal to 1/1000 with a 95 percent confidence level. The 95 percent confidence level criteria was evaluated for the facility using the dominant cut sets (hazard scenarios) derived for the different plant sections as a basis. Although it could not be shown that the facility meets this criteria for safety adequacy (due to insufficient data available), providing the results in the required form led to a useful modification of the fault tree methodology previously used.

The IITRI fault tree computer code was modified to accommodate a Monte Carlo type uncertainty analysis. Each basic event probability value on the fault tree was input as a distribution of possible values, rather than a single discreet value. These input distributions could be normal, lognormal, or a constant over a specified range. The lognormal distribution was found to be appropriate in most cases. Once the appropriate distribution shape is selected, the user need only ask questions such as "What's the highest this value could get?" to define the distribution's width. For many types of data the distribution shape and width are already available with the basic data. For example, part reliability data is generally presented with mean and 60% confidence level values. Human error probability data is presented in reference 7 with error bounds that can be approximately translated to provide a 95% confidence level. Much of the initiation sensitivity data that was generated for WADF (reference 5) was presented at the 50% (median) and 95% confidence levels.

Typically 1200 Monte Carlo trials were run for each area of the facility. On each Monte Carlo trial, single point basic event probabilities were selected off of the input distributions. The cut set (individual hazard scenario) and overall tree probabilities were then computed for that trial.

that which results in more than 10 percent loss of production capability and requires more than 3 days to repair.

Category 3 - Marginal. May cause minor injury, occupational illness or minor system damage. Minor system damage shall be defined as that which results in 10 percent or less loss of production capability or requires 3 days or less to repair.

Category 4 - Negligible. Will not result in injury, occupational illness or system damage.

The 1200 trials provided a distribution of possible output values (cutset or tree values). The mean output value was then simply the average of the computed results. The computed results for the trials were then sorted from the lowest probability value to the highest. By searching for the probability level at which 50% of the trials had a lower value, the median level could be determined. Similarly, by searching for the point where 95% of the compute values were lower, the 95% confidence level could be found. The output distributions were typically lognormal in shape. Therefore, an error factor could be defined as the 95% confidence level divided by the median value. This ratio is characteristic of the width of the output distribution, or the degree of uncertainty associated with it. Typical computer results are given in table 1 and the corresponding cumulative distribution is plotted in figure 1.

Table 1. Typical Computer Output Showing Fault Tree Failure Frequency Distribution

SUMMARY OF RESULTS FOR THE ENTIRE FAULT TREE
(FAILURES PER YEAR)

Confidence Percentile	Failure Frequency
5	1.038E-04
10	1.615E-04
15	2.256E-04
20	3.154E-04
25	3.859E-04
30	4.715E-04
35	5.579E-04
40	6.851E-04
45	8.439E-04
50	9.971E-04
55	1.152E-03
60	1.412E-03
65	1.675E-03
70	2.171E-03
75	2.767E-03
80	3.591E-03
85	4.14E-03
90	7.228E-03
95	1.270E-02
100	2.189E-01

The overall 50% confidence limit is 9.971E-04 failures per year

The overall 95% confidence limit is 1.270E-02 failures per year

The overall error factor is 12.73

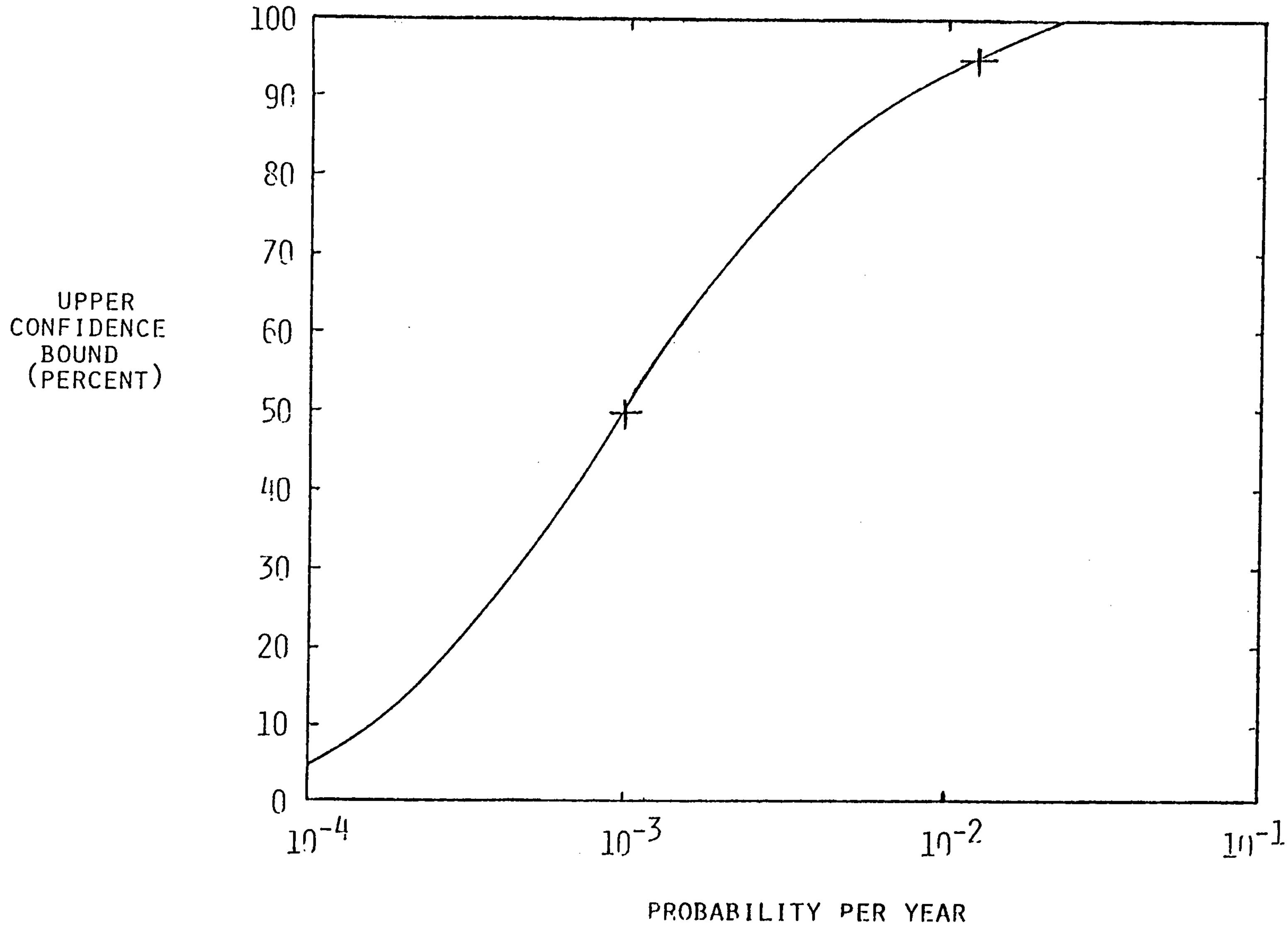

Figure 1. Cumulative Distribution for Failure Frequencies Shown in Table 2

4. RESULTS

The results of the study are summarized in table 2 (from reference 4). For each area of the facility, specific recommendations were made based on the highest probability hazard scenarios, the basic events making up those scenarios, the uncertainty in the results (error factor), and common sense. The computed probabilities were quite high in many cases due to the nature of the input data. The input data in many cases was specified conservatively because insufficient information was available to justify specifying lower input values. Thus, a relatively high value was chosen with wide error bands indicating the uncertainty in the value. In general, high probability hazard scenarios with narrow distributions of possible values (error factors less than perhaps 20) were given recommendations involving procedural and equipment modifications. Those with wide distributions (error factors greater than 10 or 20) were given recommendations involving analyses or tests to help reduce some of the existing uncertainties. Common sense also played a strong role in defining the recommendations. Finally, the recommendations were prioritized using an informal Delphi approach involving the project team members.

Today, the WADF is operating the more conventional systems where there is less uncertainty about the potential hazards. Before operating the less conventional systems, additional data must be gathered to gain assurances that the hypothesized hazards are actually of low probability or minor consequence.

TABLE 2. PRIORITIZING THE RECOMMENDATIONS

System	Recommendations, In Order Of Presentation In Section 5	Type Of Recommendation*	Frequency Based On Mean Values (/Year)	Uncertainty (Error Factor)	Priority (1-10) **
Washout/Steamout North Tower And Refining Building	1. Experiments to Better Characterize Runaway Reaction Conditions	T	7.6	10-34	9
	2. Identify/Evaluate Options to Protect Against Runaway	E	7.6	10-34	8
	3. Move Valves in Vessel Drains Closer to Vessel	E	0.837	∿ 20	7
	4. Evaluate Use of Multiple Thermocouples to Sense Onset Of Runaway	E	7.6	10-34	6
	5. Dump Vessel Content With Existing System At Onset of Runaway	P	7.6	10-34	5
	6. Plastic Tipped Lances In North Tower	E	5×10^{-3}	---	5
	7. Plastic Coated Dipstick For Separator;Keep Dipstick From contamination	E, P	1.8×10^{-3}; 6.2×10^{-2}	---/34	5;6
	8. Prevent Impeller Impact/Scraping After Major Maintenance	P	2.2×10^{-3}	---	5
	9. Inspect To Assure Screen Above Separator Is In Good Condition	P	2.2×10^{-3}	---	4
	10. Evaluate Credibility of Explosive Slug Impact Initiation In Line to Separator	A	7.7×10^{-4}	11	2
	11. Put Vacuum Trap In Line To Vacuum Pump	E	8.8×10^{-7}	---	6
	12. Clean Vessels of Contaminant Prior To Maintenance	P	2.17×10^{-3}	---	4
	13. Clean Contamination On Piping, Etc.	P	(Good Practice)	---	3
	14. Inspect Insulation On Pipes And Vessels For Contamination Getting In Cracks	P	(Good Practice)	---	3
Rotoclone Cleaners And Ductwork	1. Inspect/Clean Ducts Leading To Rotoclone	P	2.17×10^{-3}	---	4
	2. Inspect/Clean Exhaust on Rotoclone	P	2.17×10^{-3}	---	3

* Key For "Type of Recommendation" Column

T - Tests, Experiments
A - Analyses
E - Equipment Modifications
P - Procedure Modifications
C - Comments

** Priority of 1 implies important,
Priority of 10 implies critical

TABLE 2. PRIORITIZING THE RECOMMENDATIONS (Cont.)

System	Recommendations, In Order Of Presentation In Section 5	Type Of Recommendation*	Frequency Based On Mean Values (/Year)	Uncertainty (Error Factor)	Priority (1-10)**
Preparation Building (cont.)	4. Robots Expected To Require Frequent Maintenance	C	0.75	24-33	---
	5. Partition In Corridor To Protect Operators From Fragments	E	(Good Practice)		4
	6. Apply Penetrating Oil To Aid In Unscrew Operations	P	(Good Practice)		1
Accumulator	1. Inspect For Leak/Wear In Pinch Valve Rubber Boots	P	1.25×10^{-2}	12	5
	2. Inspect For Conveyor Bearing Failures	P, E	1.95×10^{-4}	---	4
	3. Do Not Adjust Conveyor Rubber Receiving Hopper Too Tight Onto Belt	P	3.5×10^{-5}	---	2
	4. Redundant Bonding For Containers During Filling	P, E.	2.7×10^{-5}	---	6
	5. Prevent Incompatible Dusts In Dust Collector and Vacuum System Ducts	P	2.6×10^{-5}	---	4
	6. Prevent Mixing of Different Propellants For Sale	P	(Good Practices)	---	6
Mechanical Removal Building - Cell 1	1. Drop Impact Tests On Primer Tubes	T	5.8×10^{-5}	15-17	2
	2. Instrumented Shearing Tests	T	8.3×10^{-7}	---	3
	3. Determine Consequence of Initiation of Primer Tubes	T	8.3×10^{-7}	---	3
Mechanical Removal Building - Cell 2	1. References Large Band Saw Recommendations	C	---	---	---
	2. Prevent Initiation Of Head Section Falling Into Tray Or Thrown After Sawing - Modify Fixture	E	13.25	11-26	7
Mechanical Removal Building - Cell 3	1. Inspection/Replacement of Cutters	P	1.3×10^{-5}	---	4
	2. Identify Safe Operating Conditions of Force/Speed For All Items To Be Processed	A, T	1.3×10^{-5}	---	5
	3. Avoid Cutting Into Internal Piping In Items	P	1.3×10^{-5}	---	5
Large Cell C	1. Hazard Associated With Cleaning Fuze After Unscrewing	C, A	---	---	5
Large Cell B	1. Use <u>Conductive</u> Plastic Cover On Sawn Items	P	1.59	13	6
	2. Identify Safe Operating Conditions of Force/Speed For All Items To Be Processed	A, T, P	0.1	17-118	5

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TABLE 2. PRIORITIZING THE RECOMMENDATIONS (Cont.)

System	Recommendations, In Order Of Presentation In Section 5	Type Of Recommendation*	Frequency Based On Mean Values (/Year)	Uncertainty (Error Factor)	Priority (1-10)**
Washout/Steamout South Tower	1. Evaluate Alternate Solutions For Processing Yellow D (Plate Out Problem)	A	2.4×10^{-2}	---	6
	2. Awareness in Yellow D Toxicity During Handling	P	4.76	---	8
	3. Evaluate Emergency Procedure for Transport Container For Yellow D Taken To Bulk Incinerator	P, C	---	---	8
	4. Analyze Structural Integrity Of Floor Grate To Hold Heavy Items	A	(Suggestion)	---	2
Bulk Explosives Disposal Building	1. Determine Compatability of Hydraulic Fluid With Materials To Be Processed	A, T	$<10^{-4}$	---	4
	2. Set Up Compatability Library at WADF	P	$<10^{-4}$	---	6
	3. Determine Potential For Initiation Of Large Pieces Of Explosive Fut Into Grinder	T	$<10^{-4}$	---	7
	4. Minimize Potential For Drum Impacts During Transport To Bulk Incinerator	P	$<10^{-4}$	---	3
	5. Install Side Chute/Gate Between Metal Detector And Grinder	E	$<10^{-4}$	---	6
	6. Analyze Structural Integrity of Floor Grate To Hold Grinder During Maintenance	A	$<10^{-4}$	---	3
	7. Decontamination of Grinder Before Maintenance	P	$<10^{-4}$	---	4
Process Water Treatment Plant	1. Determine Potential of Anthracite Coal for Inducing Runaway	T	$<10^{-4}$	---	3
	2. Do Not Use Metal Shovels For Cleaning Sumps, Etc.	P	$<10^{-4}$	---	3
	3. Keep Vessels Flooded With Water/Don't Allow Them To Dry	P	$<10^{-4}$	---	3
Preparation Building	1. Measure Concentration of Solvent Vapors As Cartridge Cases Are Opened	T, E	3.69×10^{-3}	27-31	5
	2. Install System To Monitor Water and Items In Fuze Drop Tanks	G, A	3.2×10^{-2}	∿ 15	4
	3. Do Not Store "Unsafe" Items in Cell 1	P	6.2×10^{-6}	---	6

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TABLE 2. PRIORITIZING THE RECOMMENDATIONS (Cont.)

System	Recommendations, In Order Of Presentation In Section 5	Type Of Recommendation*	Frequency Based On Mean Values (/Year)	Uncertainty (Error Factor)	Priority (1-10)**
Decontamination Building - Rotary Furnaces	1. Majority Of Hazards Are Equipment Damage	C	---	---	---
	2. Protect Propane Tank From Truck Backing Into It	E,P	3.25×10^{-6}	---	7
Decontamination Building - Tray Type Furnace	1. Inspection For Full Or Partially Full Items Is Important	P	8.28×10^{-3}	32, 122	4
	2. Install Deluge System In Bag Houses	E	6×10^{-4}	10, 14	2
Large Items, Flashing Chamber	1. Comprehensively Inspect Items at First To Assure That Flashing Works Adequately	T	237		8
	2. Use Non-Metal Rakes For Mine Cars	P	7.8×10^{-4}	21	3
	3. Keep Concrete Pad Moist To Prevent ESD	P	1.17	24.27	4
	4. Do Not Use Manual Ignition Of A Powder Train	P	4.7×10^{-2}	9-20	6
	5. Design Bracings For Items In Mine Cars To Assure Items Are Rigidly Fixed In Place	E	1.3×10^{-3}	7-17	4
	6. Train Operators To Distinguish Smokeless Powder From Explosives	P	6.2×10^{-4}	---	6
	7. Determine Criteria For Maximum Quantity of Smokeless Powder To Be Put Into Items	T	1.56×10^{-2}	38	6
	8. Inspect Incoming Items To Assure That A Total Of Less Than 10 Pounds Of Explosive Will Be Flashed	P	1.56×10^{-3}	---	6
	9. Responsibility for Firing Circuit Key and Accountability of Personnel	P	---	---	6
	10. AMC 385-100 Requirements for Cooldowns at Burning Ground	P	---	---	4
Driverless Tractor System, Off Loading Dock, And Magazine	1. Use first DLT trailer as empty spacer for thermal protection during manual operations	P	---	---	1
	2. Arrange Package/Items On DLT Carts With A Low Center Of Mass (i.e., Stable Arrangement)	P	---	---	4
	3. Do Not Use EE Rated DLT's Etc. In Areas With Exposed Explosives Or Volatile Fumes	P	---	---	6
	4. Open Box Car Doors With Care, In Case of Shifted Loads	P	3.5×10^{-2}	32	5

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TABLE 2. PRIORITIZING THE RECOMMENDATIONS (Cont.)

System	Recommendations, In Order Of Presentation In Section 5	Type Of Recommendation*	Frequency Based On Mean Values (/Year)	Uncertainty (Error Factor)	Priority (1-10)**
General Recommendations	1. Every Operation Covered By Written Procedures	P	---	---	10
	2. Comprehensive Training of Personnel	P	---	---	10
	3. Operators Certified Or Licensed	P	---	---	6
	4. Personnel Tested For Grounding Daily	P	---	---	6
	5. Scheduled Cleanups Of Plant Areas	P	---	---	6
	6. Area Surfaces Kept Wet During Maintenance	P	---	---	5
	7. Two Locker System For Plant Personnel	P, E	---	---	6
	8. Area Entry And Hot Work Permits For All Maintenance	P	---	---	7
	9. During Maintenance Hand Tools Connected To Operators Where Practical	P	---	---	4
	10. Strict Personal Cleanliness Enforced	P	---	---	4
	11. Medical Surveillance Program	P	---	---	6
	12. System Modifications Should Be Hazard Analyzed	A	---	---	6
	13. Compatability Data Library	P, A	---	---	6
	14. Validate Electrostatics Model For Dielectric Surfaces	T, A	---	---	2

* Key For "Type of Recommendation" Column

T - Tests, Experiments
A - Analyses
E - Equipment Modifications
P - Procedural Modifications
C - Comments

** Priority of 1 implies important
Priority of 10 implies critical

REFERENCES

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AMMUNITION LOGISTIC PROBLEMS IN HOT/DRY CLIMATES

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AND MAJOR N. SMITH AM RAAOC LOGISTIC COMMAND

PRESENTED BY BRIGADIER M.H. MACKENZIE-ORR OBE GM

PRESIDENT AUSTRALIAN ORDNANCE COUNCIL

Introduction

During the design of trials to establish the strength of design and safety in gun of the Cartridge 105mm Tank HESH L35A3 produced in Australia a requirement arose to determine the maximum temperatures which the cartridges were likely to experience in service use. The Australian Ordnance Council decided to conduct a trial at the Joint Tropical Trials Research Establishment (JTTRE) Innisfail to measure the temperatures reached by such ammunition when exposed to severe solar radiation in hot/dry climatic conditions.

As many of you will be aware, the environments detailed in QSTAG 360 detail upper firing temperatures based on environmental temperatures with the addition of solar radiation. During the establishment of the upper firing temperature criteria a number of conflicting criteria were produced by source documents and by the user of the ammunition. In addition, experienced tank gunners were of the opinion that particularly in ammunitioning areas, ammunition may spend considerable periods unpackaged exposed to the environment awaiting loading into armoured fighting vehicles. It was decided to obtain some factual data on the temperatures achieved by cartridges exposed to the solar load applicable to the hot/dry regions of Australia.

The trial consisted of the exposure of the instrumented cartridges with projectiles coloured black, olive, drab and white in three conditions:

a. fully exposed to solar radiation;

b. shaded from direct solar radiation by a tarpaulin with an air gap between the tarpaulin and the cartridges; and

c. completly covered by a tarpaulin in direct contact with the cartridges.

The normal meteorological data was recorded for the duration of the trial.

Trial Results

The first slide shows the maximum solar radiation measured during the test superimposed on the climatic category A2 solar radiation criteria over the period of daylight. It will be observed that the A2 solar radiation criteria are very close to the observed solar radiation loads measured during the exposure. The peak solar radiation load experienced at the Joint Tropical Trials Research Establishment exceeded that extracted from climatic category A2 by some 200 watts per metre squared at midday.

The second slide is of more concern. This shows the A2 operational temperature profile compared with the ambient air temperature measured during the trial. In this case the ambient air temperature was on average some five degrees less than the A2 operational temperature profile.

This final slide indicates the very much increased temperature rise in the propellant and at the HE interface as a result of solar loading beyond that predicted by application of the climatic category A2 criteria.

Discussion

We clearly have a problem in the hot/dry areas of Australia which comprise a very large land mass centred around the Tropic of Capricorn. Not only did the exposed projectiles exhibit a considerable increase in temperature almost independent of colour but projectiles completly covered by a tarpaulin in direct contact with the cartridges in fact exhibited slightly higher temperature increase than those exposed to solar radiation with no intervening cover. An analysis of the effect of solar radiation on the cartridges produced the results as shown on this slide.

The problem posed by the results of this trial is not really amenable to a design solution. The designers of munitions for armoured fighting vehicles or other weapons where the ammunition may be exposed to high solar radiation loads tend to design to the accepted criteria such as those published in QSTAG 360. If the design meets the published criteria there is certainly no compulsion on the designer to determine the effects should the criteria be exceeded. Such an exercise is not only enormously expensive it would be considered quite gratuitous by the majority of munitions designers who are exposed to the greatest design criterium of all - cost.

As a result of the trial the Council recommended that the user services should be aware that upper firing temperatures may be exceeded by significant amounts in the hot/dry climates of Australia and that appropriate precautions to provide ventilated shade for ammunition so exposed should be taken. Without expensive redesign of ammunition and weapons systems the problem could be handled by good housekeeping and proper care of the ammunition by the users.

Exercise Kangaroo 83

In September/October 1983 the Australian Army conducted a large sacle exercise Kangaroo 83 in the Roebourne area of Western Australia during September/October, a period when ambient temperatures are frequently well above 40°C. Aware of the problem highlighted as a result of the trial conducted the previous year, logistics personnel attempted to measure direct sun temperatures but unfortunately were issued with thermometers with a maximum capability of 50°C. Monitoring of direct sun temperatures ceased when thermometer bulbs all burst. For various reasons during the exercise considerable quantities of ammunition were stacked in the open or were transported on open vehicles covered by tarpaulins in direct contact with the ammunition. Estimates by personnel concerned with the movement of the ammunition during the exercise suggested that temperatures of around 80°C occurred over a large range of natures of ammunition dumped or transported during the exercise.

Major Smith of Logistic Command was tasked to examine the ammunition returned from the exercise to determine if unacceptable deterioration in condition has occurred. To assist in this task a summary of the possible effects of heat were provided to him and he has embarked on a program of examination and breakdown of ammunition returned from the exercise to determine its condition.

Effects of Heat

Among the effects those which were of particular relevance to the ammunition involved in the exercise include:

a. Plastic flow of high explosives even at temperatures which do not exceed their melting point. This can lead to explosive trapping in the screw threads or in cracks where subsequent firing stresses may cause premature detonation.

b. Shell filled white phosphorous which has flowed and resolidified may have modified ballistic performance.

c. High explosives are sometimes desensitized by overheating.

c. Temperature cycling can lead to penetration of seals by water vapour.

e. Some explosives particularly propellants exhibit cracking at high temperature.

f. Differential contraction and expansion may cause broken seals.

g. Cycling may permit penetration of corrosive vapours from packaging materials.

h. Condensation on electrical elements may modify characteristics.

i. Electro-chemical action at dissimilar metal junctions may occur.

j. Gassing of explosives producing high internal pressures is a feature particularly of pyrotechnics.

k. Cycling may cause distillation of nitroglycerine from double based propellants.

l. Rocket motors are particularly susceptible to large diurnal cycles producing changes in ballistic performance, degradation of bonding and inhibitors and changes in mechanical and chemical properties of propellants.

m. TNT filled shells and bombs may give rise to an exudation presenting a potential explosive and toxic hazard.

A preliminary examination of the ammunition returned showed sufficient evidence of deterioration to warrant a full scale investigation. Examples were:

a. Darkening of propellants FNH 104 and 024 from 105mm HESH cartridges with some ballistic changes on close vessel testing.

b. Cracking of the TNT of shells 105mm L41A1.

c. Functioning failures of M28 primers.

d. Reduced delays with firing device demolitions of the delay variety.

e. Bulging of closing discs with traces fitted to 76mm HE/T rounds.

Further Work in Hand

It was decided as a result of the recorded exposures and the visible evidence of deterioration in certain natures to conduct a full scale investigation of the ammunition returned from the exercise. This is to include:

a. Inspection and breakdown into major components of appropriate natures.

b. Radiography.

c. Sectioning of selected high explosive filled projectiles.

d. Static functioning tests.

e. Chemical analysis.

f. Close vessel testing.

g. Complete round functioning trials under proof conditions.

Unfortunately at this time comprehensive results of the analysis of the ammunition exposed during Exercise Kangaroo 83 are not available. On completion of the analysis, reports will be circulated through the normal channels.

Conclusions

Following the limited trial conducted by the Australian Ordnance Council on the effects of solar radiation on the 105mm Tank HESH L35A3 Cartridges it was decided that Australia should adopt procedural solutions to the problem of exceeding upper storage and upper firing temperatures in the hot/dry areas. Unfortunately, shortly after the publication of the Proceeding highlighting the need for good housekeeping for ammunition transported and stored in hot/dry conditions, a major exercise provided unwitting confirmation of the injurious effect of solar radiation detailed in the Australian Ordnance Council Proceeding.

It is clearly prohibitively expensive to design ammunition to cater for the most severe extremes of climate which may be experienced in Australia. It is clearly important that the user be aware of the limitations on the way in which munitions may be handled in hot/dry climates and of the need for sound logistic procedures.

TABLE 1 - Effect of Solar Radiation on Cartridges

ITEM NO (a)	EXPOSURE TYPE (b)	TEMPERATURE RISE ABOVE AMBIENT DUE TO SOLAR RADIATION (^{o}C) (c)
1	Full Exposure	33
2	Covered	35
3	Shaded	10

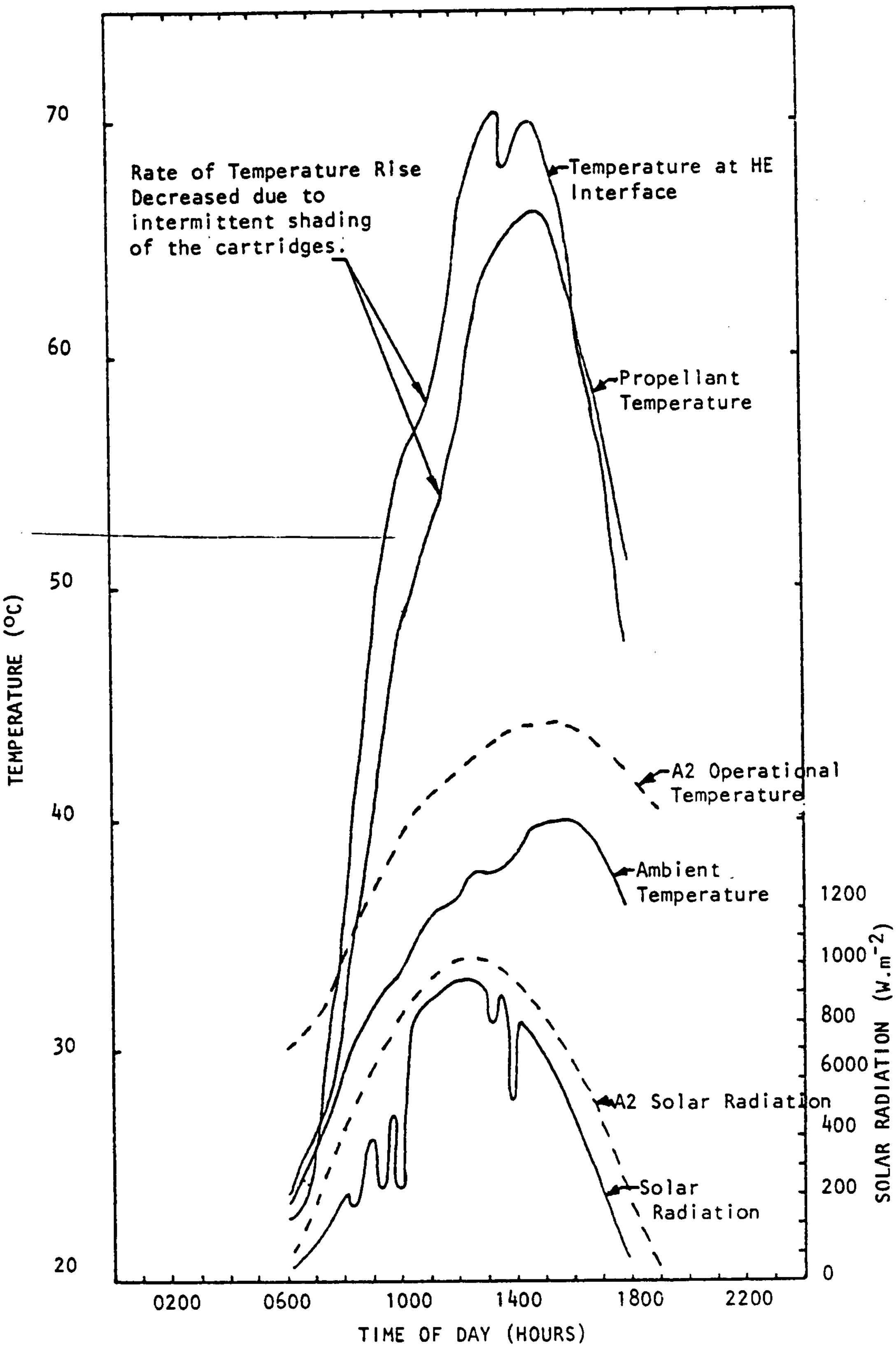


FIGURE A3. TEST RESULTS FOR 3 JAN 82.
BLACK PROJECTILE FULL EXPOSURE TO SOLAR RADIATION

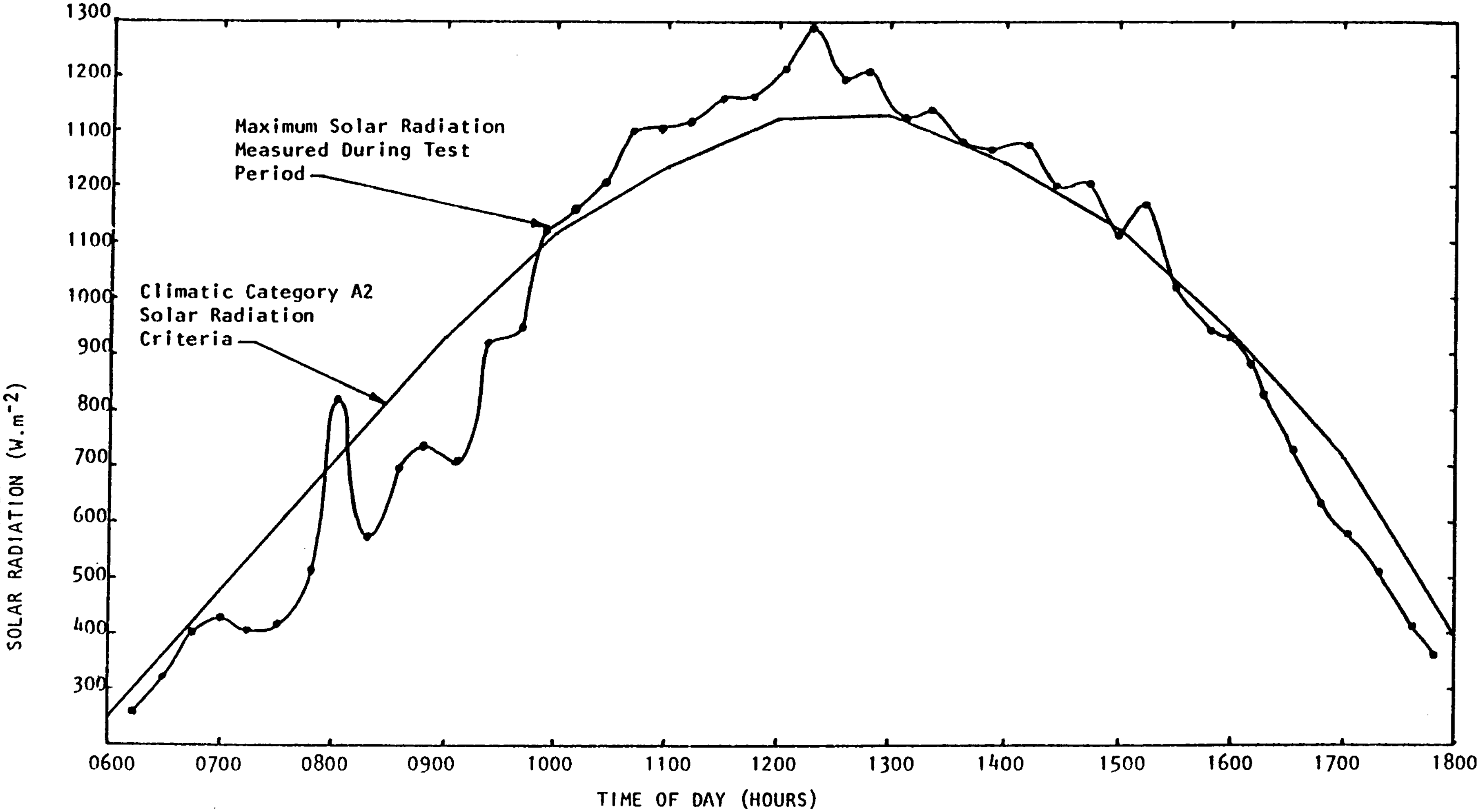


FIGURE A1 - MAXIMUM SOLAR RADIATION MEASURED DURING TEST PERIOD

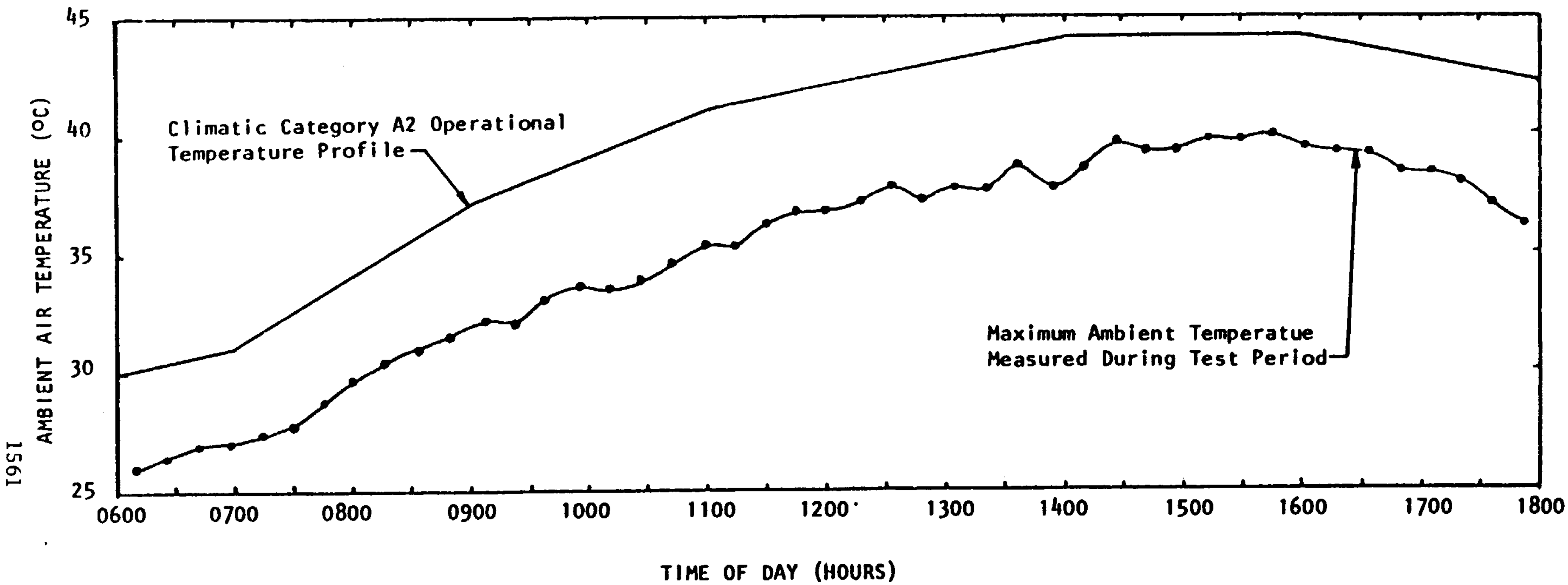


FIGURE A2. MAXIMUM AMBIENT TEMPERATURE MEASURED DURING TEST PERIOD

DEPUTY DIRECTOR LAND SERVICE AMMUNITION (UK)

STORAGE OF AMMUNITION, MISSILES, MINES AND EXPLOSIVES

UNDER NATO REGULATIONS AND IN A SAFETY

CONSCIOUS ENVIROMENT

INTRODUCTION

1. Gentlemen, my appointment is up there on the screen. I work for the Director of Land Service Ammunition (or DLSA for short), who reports to the Director General of Ordnance Services, who in turn reports to the Quartermaster General. A few words about me. I have held a number of appointments in an ammunition environment, starting off my technical career as an Ammunition Technical Officer in Germany where for two years I was responsible for the repair, maintenance and disposal of large stocks of ammunition in the rear areas of BAOR. Later I commanded an ammunition depot in Hong Kong, which was a pleasant interlude (it being on an Island in the middle of Hong Kong harbour) managing a large number of Hong Kong Chinese, but beset by the problems associated with maintaining ammunition in good condition in a hot and damp climate. Some years later I commanded a logistic battalion in BAOR and was responsible for the deployment of ammunition stocks to meet the requirements of a Division for operations and in training. More recently I spent a year as a military project co-ordinator at RARDE, in the development of explosives and pyrotechnics. Since then I have been responsible, in my present appointment, for the provision management, stock control and technical support for all the Army's ammunition stocks worldwide as well as overseeing storage and safety aspects of this ammunition.

VF1 ON (before start)

VF1 OFF

2. Though part of our Ministry of Defence, we are fortunate in our Directorate known as DLSA to live and work in the Oxfordshire countryside at Didcot. This is close to the Royal Military College of Science at Shrivenham and the Army School of Ammunition at Kineton where our Ammunition Technical Officers and Ammunition Technicians are trained. It is near a large Central Ammunition Depot also at Kineton, the Central Control Points of our Army's supply system at Bicester, and the Headquarters of an Ordnance Battalion at Tidworth which is responsible for Explosive Ordnance Disposal, Ammunition Inspections and other associated duties country-wide. DLSA has close technical supervisory links with the Senior ATO in Northern Ireland and those elsewhere in the world where our forces are serving.

VF2 ON

VF 2 OFF

3. That's sufficient background. These are the main tasks of the Directorate in which I work (Pause).

VF 3 ON

4. This talk this morning deals with the fourth principle responsibility. Being the deputy to the Army's Chief Inspector of Explosives my interest in and involvement with the subject of this talk is obvious.

VF 3 OFF

HISTORICAL BACKGROUND

5. The UK travelled a tortuous route to accept NATO regulations primarily because we had live with our own rules for many years, but also because there was a degree of resistance and quite a lot of prevarication. It was something of a jolt when one recalls that our regulations were first framed during the latter stages of the industrial revolution - not as a result of Guy Fawks as some would have us believe. As you know he tried to blow up the Houses of Parliament much earlier and we still celebrate that event every year and as fortune would have it, and you will hear later, Parliament now pays much closer attention to where and how ammunition is stored -

not, I hasten to add, just for Parliament's own protection!!

6. However, it was an unplanned explosion in the last century which had a much greater influence on our regulations and how we now regulate our military ammunition storage. This was an incident which occurred in 1874 when a barge carrying 5 tons of gunpowder exploded under a bridge on the Regents' Canal in London. A number of casulties resulted and considerable damage was done to the neighbourhood. The ensuing public outcry caused Parliament to pass the Explosives Act in June 1875. This Act contained certain legislative conditions, but in many cases exempted "military" ammunition and explosives from several important "civilian" provisions. This was particularly fortunate for the "military".

7. With these exemptions under our belt, little action was taken to increase the safety of military ammunition and explosives by improving husbandary in our depots or in the units. We were lucky and there were not many accidents anyway; none really serious enough to cause much public concern.

8. The earliest publication I can trace is "Regulations for Magazine and Care of War Materiel" issued by the Home Office in 1913. Of its 200 quarto-sized pages, only some 50 deal with the storage of ammunition and explosives. On this VF you will see how we protected metal services in our magazines. VF 4 ON

9. Clearly things had to change and both world wars had a dramatic effect on the attitudes of the military authorities towards regulations concerning the safety and storage, handling and transportation of ammunition and explosives. The authorities finally acknowledged that ammunition and explosives are inherently "dangerous". As you know, generally speaking, the greater the quantity collected together in one location, the greater the area put at risk by, say, an VF 4 OFF

accidental explosion. Our regulations were now required to minimise, if not prevent, the risk of any such accident taking place.

10. To achieve this requirement and in order to obtain conformity within our 3 Armed Services and our supporting Royal Ordnance Factories, the Explosives Storage and Transport Committee was formed in 1925 under the direction of the Ordnance Board. The advice given by this Committee is issued in the form of "prescriptions". These were quite aptly named in that "if you didn't take the prescribed medicine you might well perish". From these documents, the Army produced our still extant but copiously amended "Ammunition and Explosive Regulations". They were first published in 1953.

11. DLSA's staff prepare and publish the Army's Regulations, or VF 5 ON
A and ER's as they are commonly called. They govern the storage, (Uncover Para 1)
handling and transportation of the full range of explosive stores and some inert items in-Service. We monitor their implementation and carry out audit inspections. Where they cannot be complied with my Director, DLSA, is impowered to grant concessions, and sometimes does. I shall return to this subject later.

13. As I have said, our A and ER's are compiled with the approval of (Uncover Para 2)
Explosives Storage and Transport Committee or ESTC, and this has long
been the case. However, we now have the 1974 Health and Safety at (Uncover Para 3)
Work Act and this has introduced even more stringent legal provisions
for us in the Army and my Director wearing his Chief Inspector's hat (Uncover Para 4)
is a member of the Joint MOD/Health and Safety Executive body. This is called the Central Committee of the Defence Explosives Safety
Authority or DESA as shown on the screen. The Chairman of ESTC and (Uncover Para 5)
the Chief Inspectors of each Service and the Procurement Executive are members of this Central Committee, alongside our new found Health and Safety friends. 2nd Permanent Under Secretary (a professional

civil servant) oversees DESA activities within MOD. VF 5 OFF

13. In 1976 the United Kingdom decided to adopt NATO Regulations which we helped to draft and have agreed. In practice, our main problem arising from the new regulations was allocating our ammunition to the new Hazard Divisions of the 1.1, 1.2, 1.3 and 1.4 as they are now called.

14. Without going into too much detail, HD 1.1 covers the old Z and ZZ (high blast fragmentation effects), 1.2 some of our old ZZ and Y (projection hazards but not mass exploding), 1.3 most of our Y (fire risk), and HD 1.4 our old X (lesser explosive effects). VF 6 ON

15. The change to this new system has meant that our stocks categorised as "mass-exploding" have increased drastically at the stroke of a pen. Overnight virtually all our depot and unit storehouses holding ammunition, missiles, mines and explosives had too much Explosive Content or too little Quantity Distances. By relocating depot stocks, we have overcome most of our problems, however there was little that could be done about unit storage in many cases. VF 6 OFF

16. The introduction of the 1974 Health and Safety at Work Act, which was to have an increasing role to play in our "military" business, combined with the implementation of NATO Regulations brought about major changes to our storage and safety posture.

CURRENT SITUATION

17. DLSA has become increasingly involved with the powers and the work of the Health and Safety Executive. This involvement now covers most areas of ammunition storage, transport, handling and safety. In the military sphere this work is coordinated through DESA's Central Committee which I mentioned earlier.

18. DLSA's main task on this Committee is to interpret the legal provisions and new regulations, and ensure that the Army is not

unnecessarily hide-bound by unreasonable restrictions, particularly when it comes to "operational" matters. I can assure you that our regulations are sound, clear and well understood. At the moment we have no fears of being taken to Court, because the Crown cannot be prosecuted, and we are steadily building up close and confident working relationships with the Health and Safety people. What is changing, and changing quite rapidly and significantly, is the degree of latitude that the Services will have in the explosives and safety, storage, handling and transportation spheres in future. We are now subject to monitoring and audit from "outside" in the same way as any UK civilian explosives firm. Therefore we shall have to be even more circumspect. This will mean being even less free with our "waivers" of regulations and "concessions " to overcome storage, handling or transportation problems in UK. In overseas stations we are bound by local provisions or our own if they do not exist. In Western Europe NATO Regulations exist alongside national ones.

19. A "waiver" of regulations is necessary when, for example, no coniferous trees are allowed within an ammunition storage installation in Germany - a country covered with "protected" coniferous trees. Paradoxically trees were used during the second world war for camouflaging such sites and where we continue to use these sites this has now become a factor to consider. A "concession" is authorised when, for instance, a local village is too close to a marshalling yard on the perimeter of a depot, placing its civilian population at risk. This allows specified tonnages to be handled at any one time at the marshalling yard. We only agree "concessions" when positive action is in hand to remove the problem - in this case re-site the marshalling yard.

20. I'm sure this whole subject of safety and storage, handling and transportation is as complicated in all our countries but perhaps less so here in the United States with the vast areas of countryside which you have. It may be helpful if I say a little more about the "whys" and "wherefores" of our Army's ammunition storage.

21. NATO and British Army regulations stem from the basic premise that one day there will be an accidental explosion in a store shed, on a loading platform, at a railhead, en route to the docks, on the quayside, on board ship, or wherever. Experience and trials over the years have produced data upon which we base our methods:

a. Why should explosives storehouses and repair workshops be designed in a certain way and be constructed with certain materials? The answers to these questions have led to the modern "igloo type" storehouses for instance, which you can see in this slide of Central Ammunition Depot Kineton. We also have this type of building in our Forward Storage Sites in 1st British Corps in West Germany. The head wall and traversing around these buildings would help contain a conflagration or limit sympathetic detonation or explosion. All this is expensive and requires plenty of area. As you know, explosive debris, and fire travel quickly and can be lethal and must be limited to ensure public safety.

VF 7 ON

(Uncover Para 1).

b. Next how much explosives of which type can we store in a given building? What are the Hazard Divisions and Fire Classifications of the ammunition, mines or guided missiles to be held there? What, therefore, is the legal Explosive Content of the building? This is a picture of where they got it wrong in Zimbabwe quite recently.

(Uncover Para 2)

You will appreciate that sometimes, by putting shells with their

cartridges, fuzes and tubes or primer together in a Unit Load Container we have to store according to the component producing the highest risk, thus sometimes taking up less of the accommodation that if each were stored separately.

c. Then there is the question, what distances do we need to leave between our explosive storehouses or repair workshops (called "Inside" Quantity Distances) and what do we need to leave from a storehouse or workshop near the depot perimeter to offices, dwellings and public roads (called "Outside" Quantity Distances)? Every depot is surrounded by a series of lines on the map laying down these distances. A point to be re-made here is that by applying these Inside and Outside Quantity Distances, we use a lot of space means lengthy roads and/or railway lines, pipes to carry water for fire fighting, enclosed conduits to carry electricity, and so on. These are obviously the main reasons why ammunition storage is costly to build and maintain, and why it is inherently safe. To date our collective aim has been to provide safe storage - from the public point of view. However in the expensive 80's with a cost conscious Government, there are changes on the horizon which which concern the way we may in the future assess our safety requirements and how we may apply Quantity Distances. These are:

(Uncover Para 3)

(Uncover Para 4)

(Uncover Para 5)

(1) The introduction of "hazard and risk analysis" as a method of working out our storage and safety requirements; but even this will stand or fall on what is considered to be an acceptable civil risk. This is a decision the politicians must make and they are sensitive to the requirement as a result of the Guy Fawkes incident as I mentioned earlier.

(2) The application of the results of the Australian Stack Trials.

22. So we need a lot of money and space in this business. But why do we need to build new and better ammunition depots? Apart from the large increases in our operational stocks between now and the late 80's, the reasons vary:

a. Many existing sites were built a long time ago, under old and perhaps less stringent regulations (and incidentally before Fork Lift Trucks were invented which need much bigger door openings).

b. Some of the previous criteria used in the layout and construction of depots and storehouses were found to be wanting when tested by trials, not only from a hazard point of view but equally from the dispersal of operational stocks and the requirements of fast out-loading on mobilisation.

c. Then the nature of the stocks to be stored have changed, sometimes radically. Calibres have increased, thin-walled shells of higher explosive capacity and thus more power of fragmentation have been introduced into Service, propellants have become more potent. So Hazard Divisions and Fire Classifications have been upgraded. The Explosive Content of buildings has not necessarily changed, but the number of shell or cartridges which can be stored there may have decreased. The inside and outside distances may have lengthened.

d. Finally, unauthorised civilian building may have taken place near to the depot, thus compromising the original safety distances. VF 7 OFF

23. As I have already mentioned, another way to store our increasing stocks of more powerful ammunition or guided missiles is to "waive" the regulations, or grant "concessions". For both depot and unit

storage in the Army, DLSA is authorised to grant a "temporary" concession to overcome a specific problem in a certain location. There is no doubt that by doing so we have raised the risk to people and property. The breath of the Health and Safety people blows cold down our necks, and in any event we cannot afford politically, financially or operationally a disaster similar to that which occurred in Severomorsk, Russia, in May of this year. Severomorsk is a naval base on the Kola Peninsular 1450 Km north of Moscow. As you may know the missile storage facility blew up. Fires and secondary explosions resulting from the initial explosion took several days to bring under control. Some 1,000 strategic missiles were destroyed, 200 people killed and large sections of the facility destroyed or badly damaged.

CONCLUSION

24. I have explained: the application of explosive safety regulations to storage; the factors which determine why and how storehouses and depots must be built to comply with out complicated set of regulations which quite often change; why some of our current ammunition storage does not comply; why "concessions" are granted; and why remedial action must be taken to eliminate these. I have mentioned the impact of the new Act and the advent of Health and Safety Executive are having and touched briefly on other changes which may be in the offing.

25. Any questions?

'STORAGE OF AMMUNITION, MISSILES, MINES AND EXPLOSIVES UNDER NATO REGULATIONS AND IN A SAFETY CONSCIOUS ENVIROMENT'

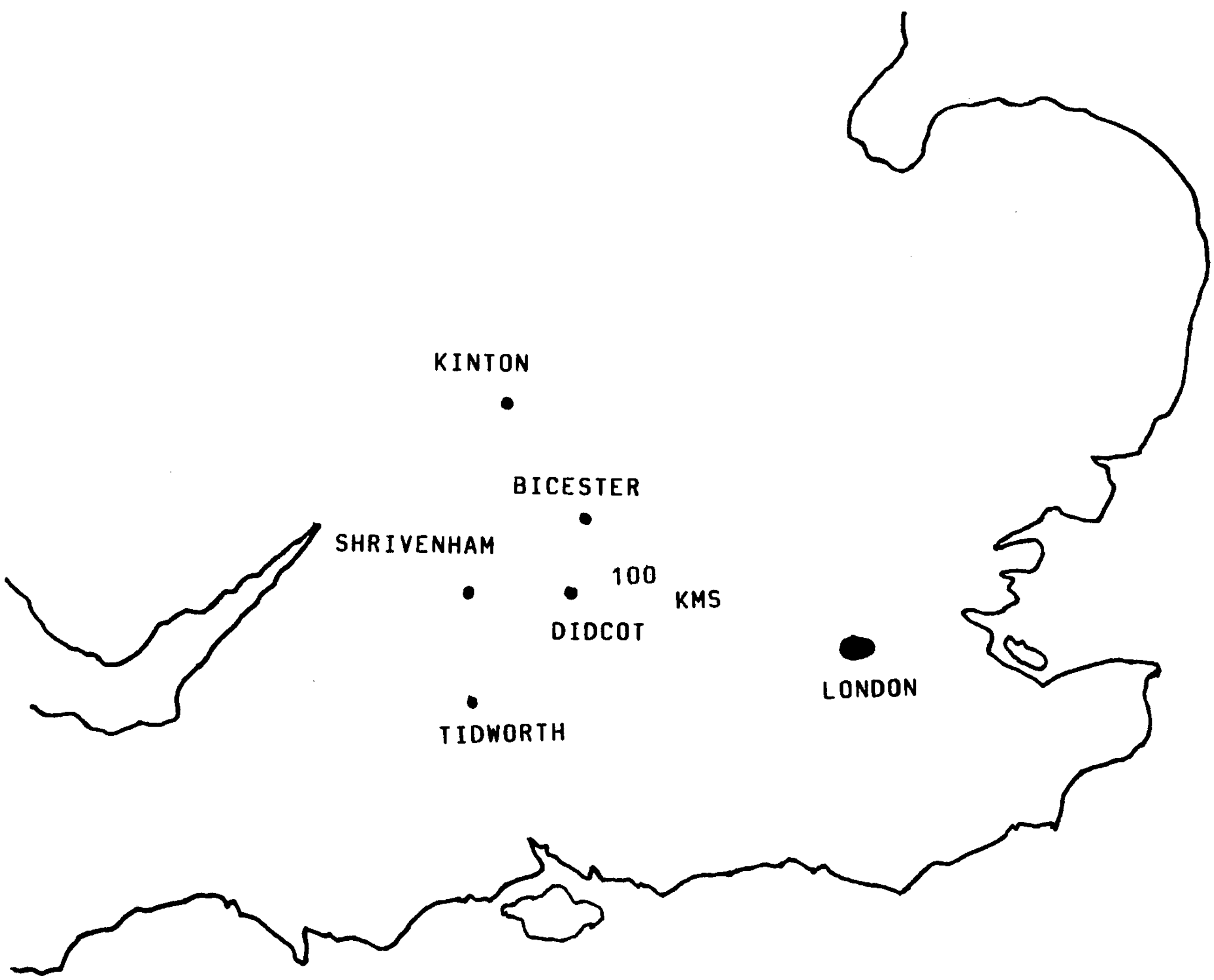
COLONEL C R PICKARD QGM FIQA MI EXP E

COLONEL LAND SERVICE AMMUNITION MANAGEMENT

(VF 2)

Where is

DIDCOT?



DIRECTORATE OF LAND SERVICE AMMUNITION

MAIN TASKS

1. Training, Qualification, Standards and Practices of Ammunition Technical Officers (ATOs) and Ammunition Technicians (ATs).

2. Equipment Management and Explosives Engineering for Land Service Ammunition, Guided Missiles and other Explosive Stores.

3. Explosive Ordnance Disposal (EOD) intelligence, operations, equipments and render safe procedures worldwide.

4. Regulating, Monitoring and Auditing Safety in Storage, Handling and Transport of Army Explosives.

THE USE OF IRON IN OR NEAR MAGAZINES

Exposed Ironwork in Buildings had to be coated with Cork Composition

"Coat the work with red lead, then apply a "good full coat" of the under-mentioned composition.

White Lead paint	22 lb
Yellow Spruce paint	44 lb
Driers, ground	12 lb
Resin, common	2½ lb
Oil, boiled, linseed	3½ gall

While the composition is wet, well cover the surface with granulated cork about the size of mustard seed, thrown by hand."

Extract from

Regulations for magazines and Care of War Materiel 1913

SAFETY AGENCIES

1. DLSA's ammunition and Explosive Regulations (A & ERs) for the Army - depots and unit storage.

2. The Explosive Storage and Transport Committee (ESTC) approves all MOD Regulations for the Ordnance Board.

3. 1974 Health and Safety at Work Act.

4. The Central Committee of the Defence Explosives Safety Authority (DESA) is a joint MOD/Health and Safety Executive Body.

5. Chairman of ESTC and Chief Inspectors of the 3 Services and PE are MOD Members.

(VF 6)

AMMUNITION HAZARD DIVISIONS

HAZARD DIVISION 1.1

Ammunition which has a mass explosion hazard.

HAZARD DIVISION 1.2

Ammunition which has a projection hazard but a mass explosion hazard

HAZARD DIVISION 1.3

Ammunition which has a pre hazard and either a minor blast hazard or a minor projection hazard or both, but a mass explosion hazard.

HAZARD DIVISION 1.4

Ammunition which presents no significant hazard.

(VF 7)

STORAGE CRITERIA

1. Design of depots and buildings, and their construction.

2. Explosive content allowed in a storehouse.

3. Inside Quantity Distances.

4. Outside Quantity Distances.

5. Safety predominates, but at a cost in space and money.

Paper Presented

at the

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Houston, Texas

28-30 August 1984

Transportability Test Requirements For Gaining Regulatory Approval

By

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Savanna, Illinois 61074-9639

Slide 1

INTRODUCTION

Thank you Mr. Teichman for the introduction. This morning/afternoon I will be presenting information on the transportability testing requirements for gaining regulatory approval to move explosives in both the wholesale and retail supply system. By wholesale, I am referring to transportation/movement by the nation's rail carriers, truckers, ocean vessels, etc. Retail system refers to movement by tactical vehicle.

Slide 2

USADACS MISSIONS

First let me provide a little background information for those of you who are unfamiliar with the mission and functions of the US Army Defense Ammunition Center and School (USADACS). The Ammunition Center was established as a separate Class II Activity at Savanna Army Depot in 1971. On 1 Jul 75 it was assigned to ARMCOM, and in January 1977 designated the USA DARCOM Ammunition Center. On 17 Jan 79, it was designated the US Army Defense Ammunition Center and School due to its diversified missions that have worldwide applications supporting the Army, Navy, Air Force and Marine Corps. My Director, Mr. John L. Byrd, Jr., reports directly to the Commanding General of AMCCOM located at Rock Island, Illinois. USADACS major missions include providing training to civilian and military personnel in ammunition logistics functions, engineering in the areas of transportability procedures, ammunition peculiar equipment (APE), and the Depot Modernization Program; two civilian career programs for ammunition (quality assurance and ammunition logistics), and providing technical assistance worldwide in the areas of receipt, storage, issue, maintenance, surveillance and demilitarization of ammunition.

Slide 3

PACKAGING, HANDLING, STORAGE AND TRANSPORTABILITY OBJECTIVES

One of the primary packaging, handling, storage and transportability objectives associated with ammunition is the prevention of explosive incidents throughout its life cycle. This is important within wholesale operations since the quantity of explosives during transportation can cause mass detonation of commercial facilities within the private sector. These incidents not only have a detrimental effect from a monetary standpoint, but also cause serious constrained relationships with commercial carriers during

future Department of Army ammunition shipments. This viewgraph shows the results of an incident in Roseville, CA, 28 April 1973, involving 18 DODX cars loaded with Navy 500-pound bombs.

Slide 4

PACKAGING, HANDLING, STORAGE AND TRANSPORTABILITY OBJECTIVES

A total of 267 railcars were lost and 5,500 structures were damaged. The total settlement for this incident approached 19 million dollars; however, the litigation costs for DOD associated with Roseville were many times this amount. The strategic effect of losing an ammunition port, supply dump or a portion of the vehicles within an ammunition supply train can be critical to the outcome of a battle. Since the final end use/destination for ammunition cannot be predetermined, packaging, handling, storage and transportation criteria must assume the worst-case condition for all development efforts.

Slide 5

TITLE 49

The basic mandate for all transportability requirements associated with explosives is Title 49 of the Code of Federal Regulations. Examples are as follows:

a. Sub-part c., titled, General Handling and Loading Requirements (railcar), Part 174.55 , states: "Except as otherwise specifically provided, each package of hazardous materials being transported by railcar must be loaded and blocked and braced as prescribed in this subchapter. For recommended methods of blocking and bracing in cars, truck beds or trailers, see Bureau of Explosives Pamphlet Nos. 6 and 6.c."

b. Sub-part b, titled, Loading and Unloading (motor vehicle) Part 177.834, states: "Containers of explosives, flammable liquids, oxidizing materials, corrosive materials, compressed gases, and poisonous liquids or gases must be so braced as to prevent motion thereof relative to the vehicle while in transit."

The Federal Motor Carrier Safety Regulation, Parts 390-397, further identify specific requirements for movement of ammo in cargo containers over the highway. Examples are as follows:

a. Containers designed for the transport of containerized intermodal cargo and having integral securement devices must be fastened to the chassis of the motor vehicle with securement devices that prevent them from being unintentionally unfastened (Reference part 393.100(e)). It further goes on to state the securement device must restrain the container from movement of greater than one-half inch in any direction and be able to resist acceleration forces up to 1.7 G's downward, 0.5 G's upward, 0.3 G's laterally, and 1.8 G's longitudinally.

b. The freight container itself, if it is directly intermodal (can be shipped by rail, road & vessel) which must be of such design and so braced as to show no evidence of failure of the container or the bracing when subjected to impact from each end of at least 8 MPH. Reference Title 49, Part 174.101 n.l. For ocean vessel movement, Part 176.130 titled, Securing and Dunnaging of Packages of Explosives, states: "Each package of explosives must be secured and be dunnaged to prevent movement in any direction. Vertical restraints are not required if the shape of the package and the stuffing pattern precludes shifting of a load." The various regulatory agency, i.e., the Bureau of Explosives of the Association of American Railroads, and the US Coast Guard of the Department of Transportion have further defined physical test requirements in order to determine and certify that the blocking and bracing used to restrain ammunition in transit is adequate and does certify its use for movement.

Slide 6

OUTLOADING MISSION

The Outloading and Storage Division of USADACS has been designing and developing standardized safe economic blocking/bracing methods for the transport of ammunition since 1941. Its mission is assigned under AR 740-1, Chapter 11, and covers the unitization of ammunition, specific handling consideration, transport by the various carriers (wholesale and retail) and storage in approved structures for ammunition. In addition, USADACS is also tasked to maintain all generated instrumentation data resulting from the various tests in support of the Department of Defense Engineering for Transportability Program, the proponency of which lies with the Transportability Engineering Agency of the Military Traffic Management Command. The end product is a DARCOM 1948 Series Drawing which is recognized worldwide as the official document applicable throughout the US Army ammunition supply system, be it commerical carrier equipment or a tactical vehicle.

Slide 7

AMMUNITION UNITIZATION, STORAGE AND OUTLOADING INTERFACE

The requirements for the development of these DARCOM 1948 Series transportability drawings comes from a variety of sources. These include:

a. The Missile Command (MICOM) located at Redstone Arsenal, for unitization, storage and outloading of missiles and large rockets.

b. Tank-Automotive Command (TACOM) located at Warren, MI for the ammunition certification testing of new tactical vehicles used in ammunition resupply.

c. Ballistics Missile Defense Systems Command located at Huntsville, AL, which requires transportation and storage documents for such systems as the SPARTAN/SPRINT, etc.

d. Belvoir Research and Development Center (BRADC) is part of the Troop Support Command (TROSCOM), which requests assistance and certification in evaluation of forklifts, slings, handling aids, etc.

e. Depot System Command (DESCOM) who often has specific requirements for the handling and storage of explosive items managed outside of Department of Defense. An example includes the recent handling system and storage rack for the Caster IV rocket motors associated with the DELTA rockets managed by NASA; and, finally

f. Our parent organization, the Armament, Munitions and Chemical Command (AMCCOM) which includes the Chemical Research and Development Center at Aberdeen Proving Ground, and the Armament Research and Development Center located at Picatinny Arsenal. These two R&D centers are responsible for toxic, nuclear as well as conventional ammunition development. Interface with these organizations and the various PM's and other various Army Training and Doctrine Commands occurs early in the development cycle. The Training and Doctrine Command has just recently identified a Munitions Systems Manager for coordination of all combat service support development. This office is co-located with the Missile Munitions Center and School at Redstone Arsenal, Huntsville, AL.

Once these tasks are received and the various priorities assigned, USADACS is responsible for the appropriate design, transportability testing, final drawing formulation and resultant final regulatory approval of specific procedures. Constant interface is required with the following regulatory agencies in order to obtain the signatory approval:

a. Transportation Engineering Agency at Newport News who reviews and approves all open-top car loading procedures in coordination with the Association of American Railroads.

b. The Bureau of Explosives of the Association of American Railroads, whose representatives witness transportability tests and sign all carloading, truckloading and containerization drawings for common carrier equipment.

c. The US Coast Guard of the Department of Transportation who provides signatory approval on all drawings pertaining to containerized ammunition in intermodal containers, and

d. The 4th Transportation Command, Belgium National Railway and Deutz Bundesbahn Railway of the Federal Republic of Germany, who review and approve all DARCOM 1948 Series drawings for use on European-type railway equipment. Once the appropriate testing has been accomplished and regulatory approval of individual drawings has been obtained, the Director of USADACS is delegated responsibility for signatory approval by order of the Commanding General of the US Army Materiel Command. Reproduction and pinpoint distribution to those installations/agencies/activities with a mission for receipt/storage/issue of ammunition is accomplished by USADACS.

Slide 8

TESTING REQUIREMENTS (Packaging)

During new item development, various standardized tests are performed to determine the safety and operational capabilities of the packaged and unpackaged item. Typically, the Armament Research and Development Center (ARDC) prepares a test program request (TPR) which is submitted to the Test and Evaluation Command (TECOM) at Aberdeen Proving Ground for action. TECOM test operations procedures (TOPS) utilized have been derived from MIL-STD-331A which identifies uniform environmental and performance tests for use in development and production of fuze components. The tests are designed to simulate possible shocks and vibrations that could be encountered throughout the anticipated logistical supply system including CONUS surface transportation, shipboard loading, tactical transport, and severe handling in the battlefield. The ammunition item must remain safe and operable to be considered acceptable after being subjected to all tests except the 40-foot free fall drop test (shiploading accident) and the 350-foot free fall drop test (malfunctioning parachute during air delivery). In these cases, the item must only survive to the extent that it can be safely handled and disposed of. Additionally, burn tests are performed to determine degree of detonation and propagational effects of each end item so the appropriate hazard classification can be assigned.

Slide 9

UNITIZATION

As previously stated, development of new ammunition packaging is accomplished for the Army at one of the R&D centers, i.e, Picatinny Arsenal or Aberdeen Proving Ground. The determination of the most appropriate configuration for palletization/unitization is accomplished by USADACS personnel. A typical example is the new square end propelling charge container developed at Picatinny Arsenal, which will provide one step easy access to individual charges. USADACS engineering personnel utilizing their expertise/knowledge in the various life cycle environments associated with ammunition logistics determine the most appropriate unitization configuration. This determination takes into account production, storage in the various approved type structures, transportation in the various commercial and tactical carriers, handling by the various slings associated with port and tactical operations, and finally transportability in a tactical environment.

Slide 10

TESTS TO DETERMINE STRUCTURAL RELIABILITY OF UNIT LOADS

The criteria for the development of palletization/unitization procedures and associated testing is covered in MIL-STD-1660 (a document written jointly by Army, Navy and Air Force personnel to insure interoperability of ammunition produced for all services by the Single Manager for Conventional Ammunition, who is the Army). Standardized tests conducted in accordance with MIL-STD-1660 verify the structural reliability of unitization procedures

developed for loads of ammunition items. These tests ensure that the unit loads are capable of withstanding all storage, handling, and transportation environments which will be encountered throughout the anticipated logistics life cycle. The tests are designed to simulate stacking loads (16 ft high), shocks (2-foot drops), vibrations (3 to 5 cyles per second), and impact forces (7 to 10 feet per second) which are common to these environments, and to assess the durability and stability of the unit loads. The tests also determine compatibility with transportation vehicles and compatibility with the mechanical handling methods (forklift, pallet truck, and sling) which will be used. Also, note that the tests are derived from proven Federal test methods and are in compliance with NATO Standardization Agreement (STANAG) 2828 requirements.

Slide 11

Palletization/Unitization Tests (Upper left) -

Paragraph 5.4.3.1 of MIL-STD-1660 defines edgewise drop test requirements in accordance with Method 5008 of FED STD 101. The test is designed to simulate accidental rough handling and requires 24" drop for unit loads up to 3,000 lbs and 12" drop for loads exceeding 3,000 lbs.

Incline - Impact Test (Upper Right) -

ARDC developed an improved package for the 2.75-inch assembled rocket as a replacement for the 25-round wooden box. The new 19-round steel drum was developed to reduce the time and manpower requirements to re-arm platoons of COBRA helicopters with 2.75-inch rockets during mid-intensity warefare. The resupply container will support attached helicopter units at a forward area refueling site. In the view depicted, the two container unit load is positioned on an incline-impact tester ready for tests to determine the adequacy of the unit load for withstanding forces which could be incurred during shipment within a boxcar. Paragraph 5.4.4 of MIL-STD-1660 defines incline-impact test procedures which require 7 ft/second impact velocity for most standard issue ammunition unit loads and 10 ft/second impct velocity for fleet issue unit loads. (Ref Method 5012 of FED STD 101).

Repetitive Shock Test (Lower Left) -

This unit load is shown undergoing vibrational tests. This wirebound box package has been developed by ARDC for the M724A1 105mm tank rounds. Since the wirebound box is not as structurally supportive as the conventional nailed wooden box, certain provisions must be made during unitization to achieve a stable load. Restrictive criteria include box overhand, box orientation, strapping location, and unit height. USADACS tested several palletization configurations to collect and evaluate data for the wirebond box unitization concept. The configuration shown consists of 15 boxes and a wooden spacer assembly on a standard (Style 1A) 35" x 45-1/2" pallet. Paragraph 5.4.2 of MIL-STD-1660 identifies the repetitive shock test which simulates random vibration incident to rail and highway transportation (Ref FED STD 101-Test Method 5019).

Stackability Test (Lower Right) -

The test and evaluation of unit loads as conducted at the US Army Defense Ammunition Center and School includes a compression test. The item shown being tested is an XM268 demolition blasting kit packaged into a wirebound container. This unit package was developed by the US Army Armament Research and Development Center and was tested by the US Army Defense Ammunition Center and School to aid in the preparation of blocking and bracing procedures for truck and railcar shipments. This stackability test identified in paragraph 5.4.1 of MIL-STD-1660 simulates the long term stacking of identical units in storage or stacking to a height of sixteen feet in breakbulk loading of ships.

Slide 12

TRANSPORTABILITY TESTS REQUIRED

Rail Impact -

The USADACS 4, 6, and 8 MPH rail impact test is used to evaluate transportability characteristics of Class V material, restraint procedures, and related equipment to gain the regulatory agencies' (Association of American Railroads (AAR) - Bureau of Explovsies (BOE)) approval for movement of the designed loads in the conventional railroad, boxcar, flatcar, and trailer-on-flatcar (TOFC) mode. Container loads of ammunition for intermodal shipment must receive additional approval from the US Coast Guard.

Road -

Specimen loads restrained on a semitrailer van, a semitrailer flatbed and other commercial and tactical vehicles are subjected to the USADACS transportability road course. Intermodal containers must also traverse the road hazard course on the appropriate vehicle. The US Coast Guard is the approving regulatory agency for intermodal containers, while the Association of American Railroads - Bureau of Explosives approval is required for the movement of Class V material over the roadway.

Tilt -

An intermodal container load restraint system is subjected to an 80 degree tilt test before regulatory approval is granted by the US Coast Guard. This test induces up to one G force into the sidewall of the container. USADACS has also designed and built a Shipboard Transportation Simulator (STS), a dynamic testing device which will be used for further validation of a container design and cargo restraint systems for containerized loads as well as cargo restraint systems for breakbulk loads.

Slide 13

TRANSPORTABILITY TESTS

Rail Impact (upper left) -

Commercial loads of ammunition blocked and braced for shipment are subjected to USADACS transportability testing to gain the regulatory agencies' approval (Association of American Railroads - Bureau of Explosives and the US Coast Guard, Office of Hazardous Materials). This scene shows a commercial 40-ft semitrailer using the new Pallagard Restraint System in TOFC mode awaiting the 4,6, and 8 MPH forward and 8 MPH reverse impacts into a string of 5 empty boxcars (standard AAR test). This rail impact test procedure simulates the worst-case condition that may be encountered during rail humping operations (switching operations during the makeup of trains) or slack run-out upon a train's initial movement. Forces incident to rail impact tests are 6 G's @ 50 millisecond duration against the ammunition packaging on the impacted end of standard conventional boxcars and 2-1/2" G's @ 250 millisecond duration against the ammunition packaging on the impacted end of TOFC trailers/intermodal containers.

TRANSPORTABILITY ENGINEERING TESTS

Road Test for Line Haul (upper right) -

Formal agreements between the Commanding Generals of AMCCOM and TACOM now require that new vehicles under development that will transport ammunition must be submitted for USADACS certification testing to verify that they can safely restrain and transport ammunition within the intended transportation environment. This view shows the new M871 tactical semitrailer loaded with inert small arms ammunition preparing to enter the hazard course.

Combat Service Support Test (lower left) -

For years USADACS has been preparing the detailed tiedown procedures for nuclear weapon items to insure the safety of these unique and sensitive items during transport. The DARCOM 1948 Series drawing becomes an integral part of the Weapons System Manual and is used by both the operator responsible for the weapon system and Surety Operational Inspection (SOI team) to determine proficiency of any given unit. In addition, there has been increased emphasis on the tiedown restraint of conventional ammunition in tactical vehicles during both training and peacetime and in preparation for transition to war, including uploading of the unit basic load.

TRANSPORTABILITY TESTS

Shipboard Transportation Simulator (STS) (Lower Right)

USADACS has had excellent success with testing programs for containers. Theoretical calculations have been validated by empirical test results. This work has contributed to the success of the Containerized Ammunition Distribution System (CADS).

USADACS has also designed and built a new innovation in container testing - A Shipboard Transportation Simulator (STS). This equipment, to be fully operational 1st Qtr FY 85, will perform dynamic tilt tests and further aid in the validation of container design and the respective cargo restraints utilized. There is a good possibility that some of the currently approved dunnage configurations for intermodal containers can be modified to reduce a portion of the dunnage due to the lower applied G forces from this dynamic testing device when compared to current US Coast Guard test requirements. In addition, provisions have been made to add a breakbulk platform to evaluate TM 55-607 type stowage procedures. The STS is designed for 45,000 lb capacity, 45° max roll angle and 13 second roll period. US Coast Guard approval of containerized ammunition restraint procedures currently requires an 80° tilt test. The container sidewall must restrain the weight of the lading when tipped to within 10° of the ground without permament deformation. This test procedure creates a maximum load of 1 G against the container sidewall, which is greater than the .6 G design standard for commercial intermodal containers; therefore, dunnage material is currently required to augment the existing sidewall strength of intermodal containers for the safe movement of ammunition.

If all transportability tests (rail impact, road and tilt) are successful, regulatory approval is granted pending completion of signatory approval and distribution of the final DARCOM 1948 Series drawings.

Slide 14

TRANSPORTABILITY ROAD COURSE

This schematic depicts the USADACS road course test which is conducted on all commercial and tactical vehicles transporting ammunition. The tractor/chassis/container/trailer, etc. combination initially traverses a 200 ft segment of concrete paved road with railroad ties spaced 8' and 10' apart and projecting six inches above the level of the road surface. Each specimen load is driven across the hazard course of railroad ties twice at a speed that will produce the most violent vertical and side-to-side rolling reaction obtainable (approximately 5 MPH). Then a 30 mile road trip over available depot rough roads consisting of gravel, concrete, asphalt, curves, cattle grates, stops, and starts is performed. Panic stops on a 7% downgrade at 5, 10 and 15 MPH in a forward direction and 5 MPH in a reverse direction are accomplished. The hazard course of railroad ties is again traversed twice before being subjected to the last portion of the road course. The last portion (washboard course) is optional, and consists of a 300' long road of steel rail sections spaced on 26-1/2 inch centers and embedded in concrete to protrude two inches above the road surface. This course produces a violent response when the resonance frequency of the vehicle suspension system is reached (normally 2-3 MPH) and validates effectiveness of the restraint system. This total course is designed to create the worst-case condition for both commercial and/or tactical vehicle use. Each course, washboard and hazard, has the capability to develop 4 G's vertical force. In addition, the hazard course will generate approximately 1-1/2 G's of lateral force due to swaying action of the vehicle as it passes thru the alternating ties.

Slide 15

TEST INSTRUMENTATION IN ACCORDANCE WITH AR 70-47

USADACS acquires and maintains various instrumentation data associated with the various tests in support of the Department of Defense Engineering for Transportability Program. Various instrumentation data such as shock, vibration, stress, strain, displacement, load cell forces, etc., are transmitted via a portable telemetry package mounted on the test vehicle. The telemetry data is received and permanently recorded in a mobil instrumentation van for subsequent analysis. Various analysis methods are available including immediate oscilligraphic readout or subsequent data reduction through an analog to digital converter using various filtering methods to generate the final report. This equipment is capable of recording both low and high frequency phenomenon as it is also used to record and analyze overpressure data resulting during explosive safety tests of ammunition peculiar equipment (APE) items.

Slide 16

APPROVAL AUTHORITIES

Various regulatory approval authorities are participating in the conduct of each test and also review in detail each specific drawing. After review of the drawings, the authorized representative from each agency provides signatory approval on the cover page of the drawing which indicates their concurrence with the procedure. Typical examples include:

a. The Director of Transportation AMCCOM, US Coast Guard and Bureau of Explosives representatives approving all intermodal container drawings.

b. Director of Transportation and Engineering Support Directorate representatives at AMCCOM signing all unitization drawings.

c. European railcar procedures must conform to the regulation governing the reciprocal use of wagons in international traffic (RIV). This coordination is currently accomplished by the US Army 4th Transportation Command in Oberuso, Germany. Once the appropriate government/regulatory agencies have reviewed and signed the drawings, the Director of USADACS has been delegated final approval by the Commanding General of the US Army Materiel Command, and thus is the final approval authority.

Slide 17

SURFACE TRANSPORTATION

USADACS provides transportability drawings covering all the various modes of surface transportation in both the wholesale and retail environment. This slide depicts the variety of commercial as well as tactical vehicles, including ocean vessels, which are involved in the supply and resupply of

ammunition. Department of Army Pamphlet No. 310-24 titled, Index of Storage and Outloading Drawings for Ammunition Commodities, provides a list of all of the storage and outloading drawings that have been prepared and are available for use at depots, plants, ports, posts, camps and stations to insure safe economic and standardized procedures for the transport of ammunition. Navy outloading drawings commonly referred to as WR's and Air Force drawings commonly referred to as TO's are available from the Navy and Air Force, respectively.

Slide 18

OUTLOADING BOXCAR

The following are examples of typical test loads/procedures designed, developed and tested at USADACS. This slide shows the Multiple Launch Rocket Support (MLRS) System loaded in a conventional boxcar during rail impact tests.

Slide 19

OUTLOADING COMMERCIAL TRUCK

This slide depicts a commercial truckload of Air Force 30mm ammunition just prior to its entering the hazard course. It is imperative during any transportability testing that the vehicle selected for transport simulates as closely as possible the actual vehicles that will be used during subsequent transport.

Slide 20

OUTLOADING COMMERCIAL CONTAINER

This slide depicts the Multiple Launch Rocket Support System (MLRS) restrained in a commercial intermodal container using the Army-developed wood dunnage system. Off the shelf, commercial containers do not have sufficient end wall strength to restrain ammunition during the standard AAR-BOE trailer-on-flatcar rail impact tests. Therefore, a significant amount of design and dunnage components are necessary to insure safe transport.

Slide 21

SHIP LOADING - BREAKBULK SHIP

Although USADACS does not provide stowage drawings for conventional ammunition in breakbulk ships, it does provide detailed stowage requirements for high-cost missile items developed by the Missile Command. These detailed procedures are used by the stevedores at Military Ocean Terminal-Sunny Point as an example, to insure that the blocking and bracing techniques for stowage of these items do not damage weaker parts of the missile container and

preclude possible resultant damage to the missile item itself. In addition, recommended handling/slinging methods are also provided to insure protection of the item.

Slide 22

TYPICAL TRANSPORTABILITY TEST ITEMS

LVS (upper left)

The Logistics Vehicle System (LVS), or Dragon Wagon, as it is referred to by the Marine Corps, was recently certified for the transportation of ammunition by both public highway and railcar.

WSC/HARC (upper right)

Two nuclear weapon items associated with the surety of nuclear weapon systems were recently tested. These included the Weapons Security Container (WSC) and the Helicopter Accident Resistant Container (HARC) being transported on an M871 semitrailer as shown here.

MPS (lower left)

This slide depicts the 6 ft high open-top gondola-type container currently being procured by the Marine Corps in support of the Marine Prepositioned Ship (MPS) Program. The transportability test conducted at USADACS resulted in recommended changes to the engineering design of the container to insure it is acceptable for its intended transportation environment.

SUSV (lower right)

This portion of the slide depicts the Small Unit Support Vehicle (SUSV) currently under limited procurement in support of land combat forces in Alaska and Italy. The purpose of this system is to provide safe transport of both ammunition and personnel in an arctic environment. Again, the results of USADACS tests recommended changes/modifications to the vehicle in order to insure full transportability.

Slide 23

NEW TRANSPORTABILITY TEST FACILITY

The ability of USADACS to respond to high priority transportability test programs is becoming increasingly important. Particularly with the advent of all of the new vehicles and weapon systems being developed by the Army Materiel Command. In order to insure continued and improved responsive capability, USADACS has identified a requirement for a transportability test facility building that will provide improved capability, particularly during

inclimate weather. An MCA project slightly in excess of 1 million dollars has been approved by the Army Materiel Command for FY87. The improvements will include a modern laboratory for palletization/unitization tests, heated instrumentation bay, covered loading docks for both rail and motor vehicle, consolidation of various inerts associated with transportability tests, and ability to simultaneously conduct tests on one vehicle while loading another.

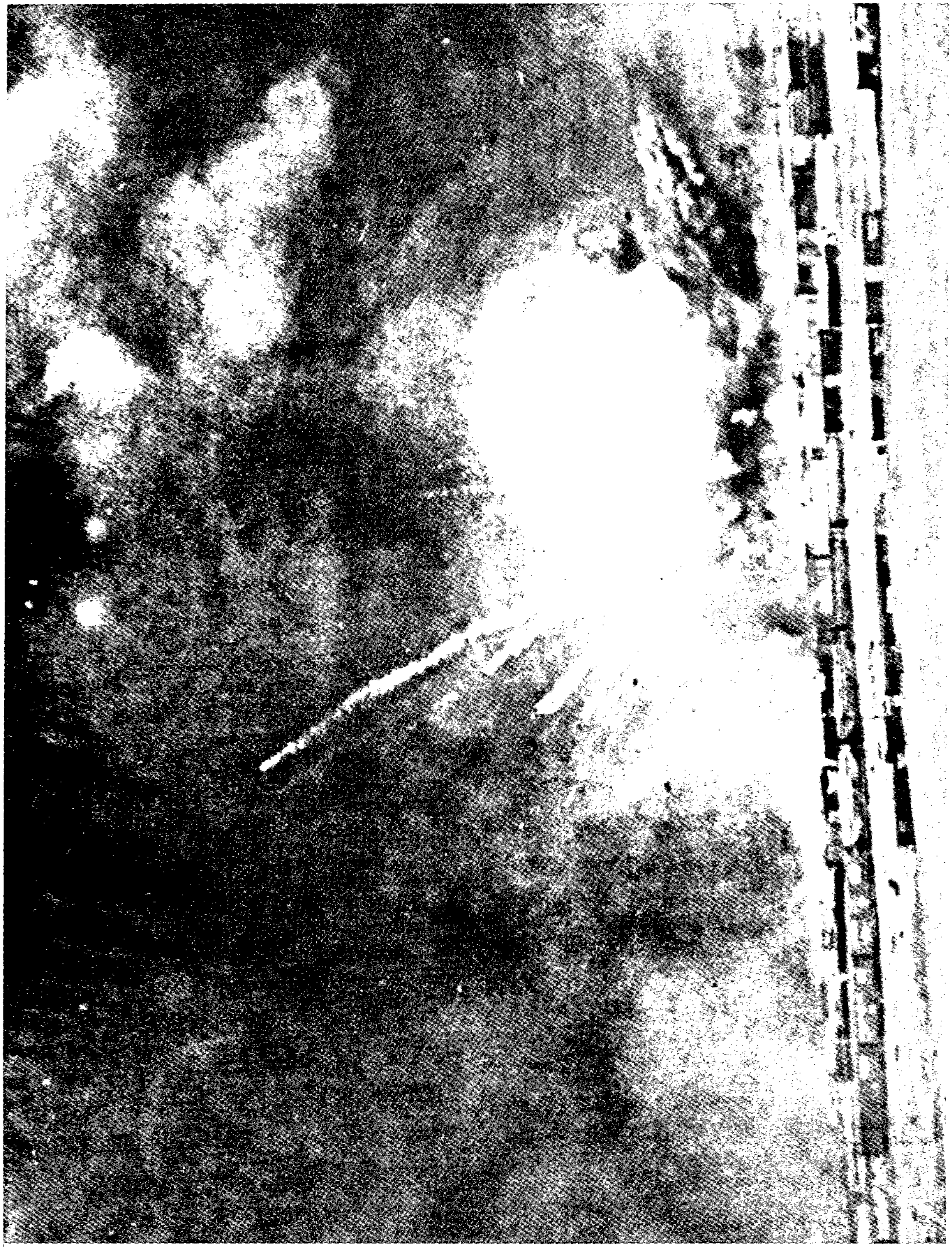
SUMMARY

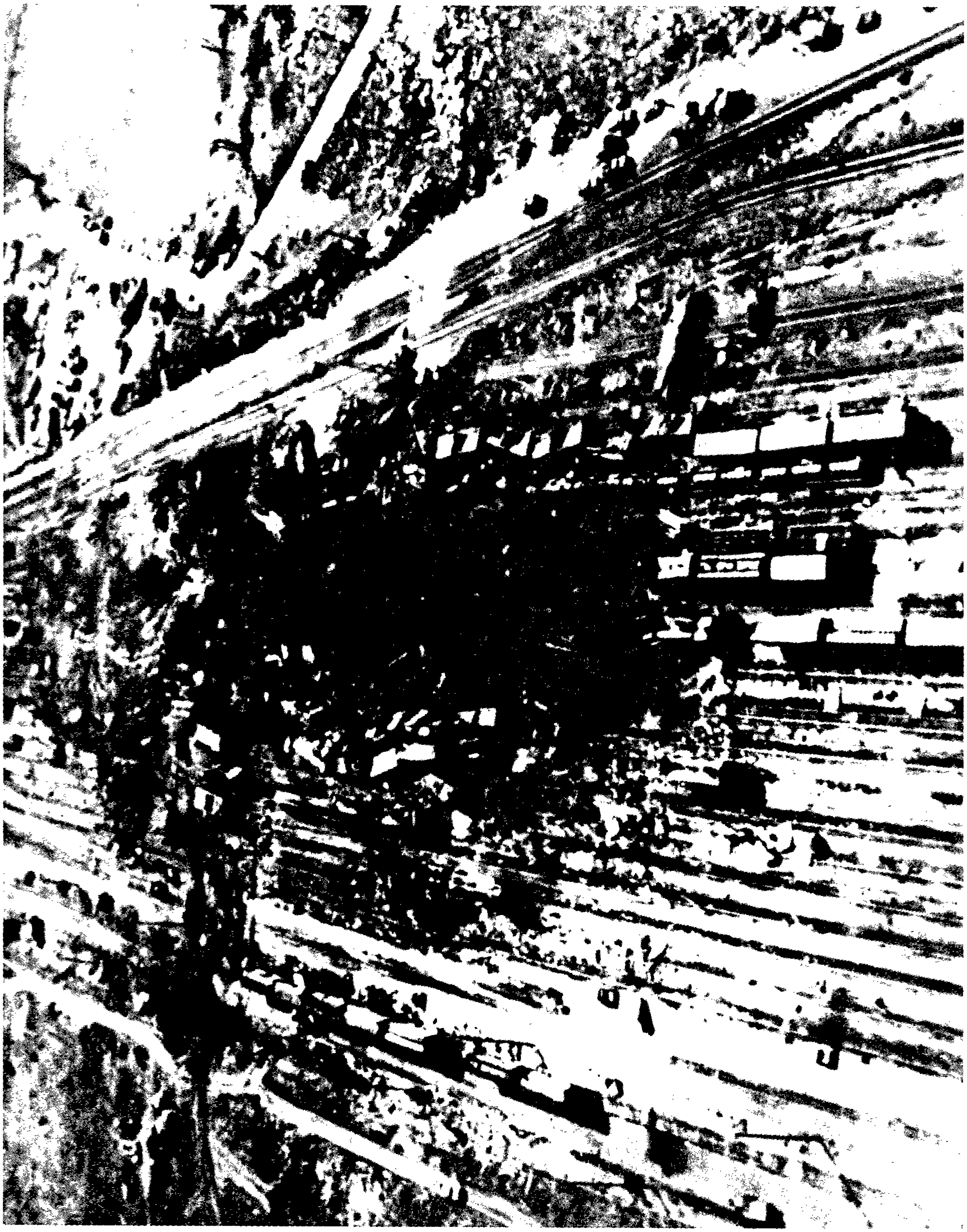
In summary, I have attempted to outline where the basic requirement for transportability tests originates (Title 49), the variety of agencies involved in the conduct and review of transportability tests, and show you how the Army under AR 740-1 administers its transportability program for the transport of ammunition. The mission being accomplished at USADACS is not new, as the program was established in 1941 and has been ongoing ever since. Improvements with regard to type of tests, instrumentation data, and facilities themselves are constantly being made to provide a better product and insure incidents such as those occuring at Benson, AZ and Roseville, CA do not occur with ammunition moving under the cognizance of the Department of Army. The outloading procedures developed by USADACS are used worldwide; however, very rarely does the user understand the reason for the various detailed procedures and resultant dunnage components used to restrain ammunition. I hope this presentation has provided insight to each one of you regarding a mission that we feel is very important to the Department of Army and our national defense. Thank you.

TRANSPORTABILITY TEST REQUIREMENTS FOR GAINING REGULATORY APPROVAL

21ST EXPLOSIVES SAFETY SEMINAR

PRESENTED BY: WILLIAM ERNST





code of federal regulations

Transportation

49

PARTS 100 TO 177

Revised as of November 1, 1983

CONTAINING
A CODIFICATION OF DOCUMENTS
OF GENERAL APPLICABILITY
AND FUTURE EFFECT

AS OF NOVEMBER 1, 1983

With Ancillaries

Published by
the Office of the Federal Register
National Archives and Records Service
General Services Administration

as a Special Edition of
the Federal Register

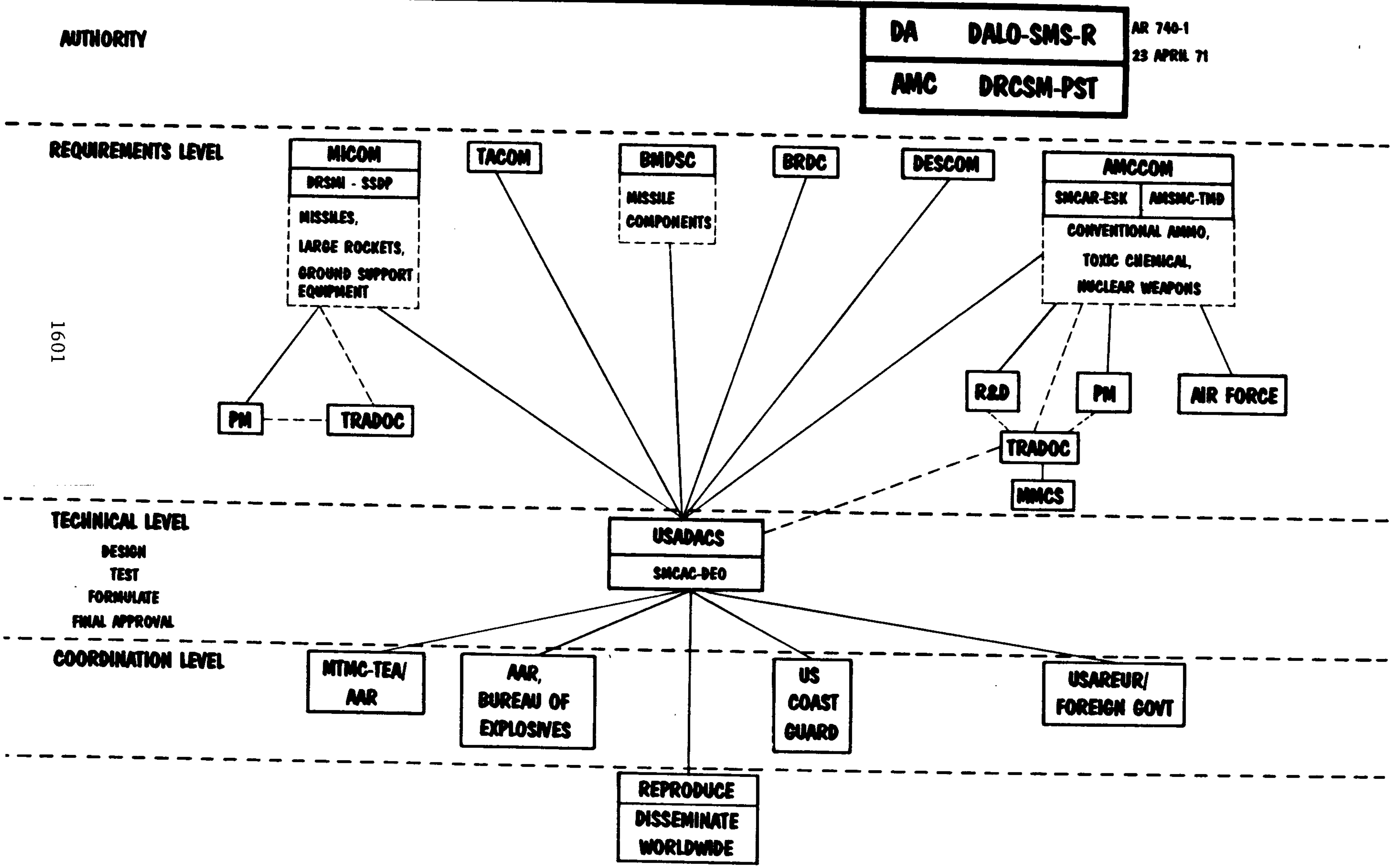
STORAGE AND OUTLOADING DIVISION

UNDER AR 740-1 CHAPTER 11 USADACS PROVIDES SAFE ECONOMIC AND STANDARDIZED METHODS FOR :

- UNITIZATION OF AMMUNITION ITEM
- AMMUNITION HANDLING OPERATIONS
- TRANSPORT OF AMMUNITION AND GROUND SUPPORT EQUIPMENT BY
  - RAIL
  - MOTOR CARRIER
  - INTERMODAL CONTAINERS
  - TACTICAL VEHICLES
  - SHIPS
- STORAGE OF AMMUNITION IN APPROVED STRUCTURES
- MAINTAINING ENGINEERING INSTRUMENTATION DATA IN SUPPORT OF THE DOD ENGINEERING FOR TRANSPORTABILITY PROGRAM

SPECIAL NOTE: DARCOM 1948 SERIES DRAWINGS ARE OFFICIAL DOCUMENTS APPLICABLE THROUGHOUT THE US ARMY AMMUNITION SUPPLY SYSTEM

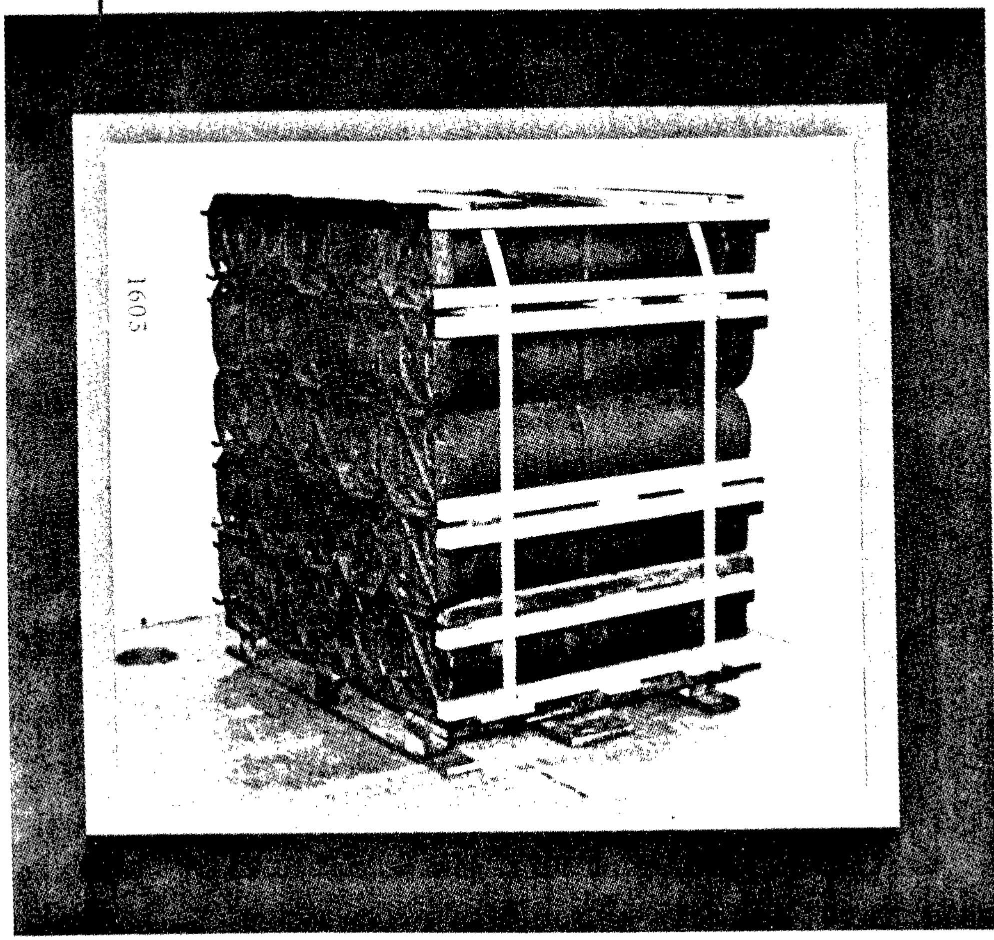
AMMUNITION UNITIZATION, STORAGE, & OUTLOADING INTERFACE

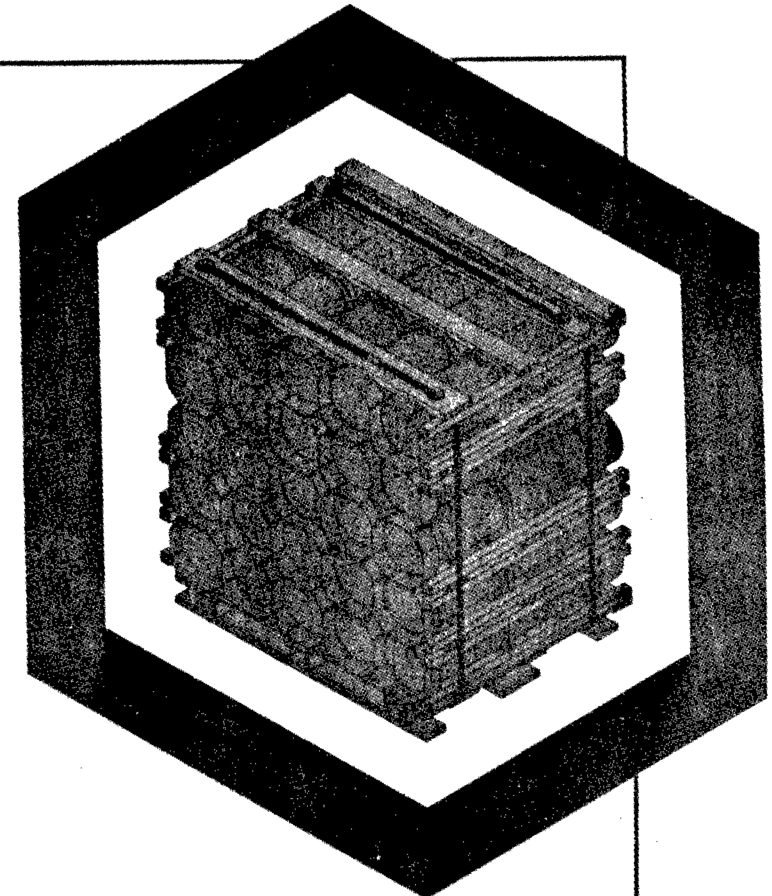


TESTING REQUIREMENTS (PACKAGING)

- ARRADCOM/TECOM (MIL-STD-331A)
  - UNPALLETIZED (7 FOOT FREE FALL DROP) INDIVIDUAL PACKAGE
    (5 FOOT FREE FALL DROP) WITHOUT PACKAGE
  - AIR DELIVERY (87 FOOT FREE FALL DROP) AIR DROP PALLET
  - SHIPBOARD SAFETY (40 FOOT FREE FALL DROP) STD UNIT LOAD
  - VIBRATION TESTS (SECURED & LOOSE)
- BURN TESTS (TO DETERMINE HAZARD CLASSIFICATION)

UNITIZATION – 4-WAY ENTRY PALLET





PROPELLING CHARGE IN PA92 CONTAINER

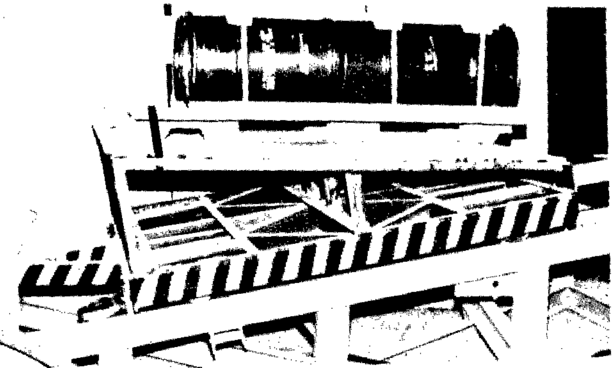
TESTS TO DETERMINE STRUCTURAL RELIABILITY OF UNIT LOADS

MIL STD 1660 PARA NO	TEST	CROSS REFERENCE
5.4.1	STACKABILITY	STANAG 2828
5.4.2	REPETITIVE SHOCK (VIBRATION)	METHOD 5019 OF FED-STD 101
5.4.3.1	EDGEWISE DROP TEST	METHOD 5008 OF FED-STD 101
5.4.4	INCLINE IMPACT TEST	METHOD 5012 OF FED-STD 101
5.4	TEMPERATURE	MIL STD 648
5.4.5	TIPOVER TEST (STABILITY)	METHOD 5018 OF FED-STD 101
5.4.6	FORKLIFTING TEST	METHOD 5011 OF FED-STD 101
5.4.7	PALLET TRUCK TEST	STANAG 2828
5.4.8	SLING COMPATIBILITY TEST	STANAG 2828
5.4.9	DISASSEMBLY TEST	STANAG 2828

SPECIAL NOTE: TESTS IN MIL STD 1660 FULFILL THE TEST REQUIREMENTS OF STANAG 2828

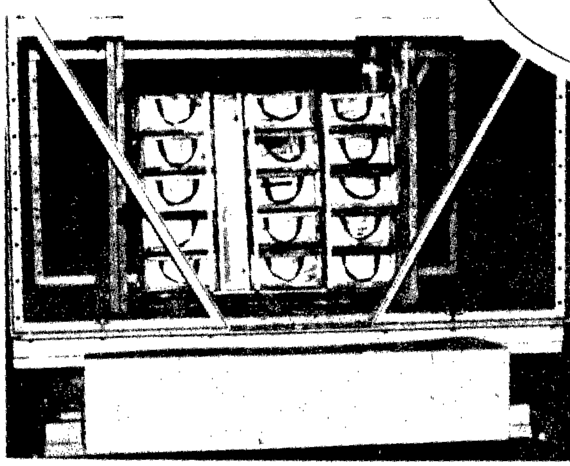
PALLETIZATION / UNITIZATION TESTS

DROP / ROUGH HANDLING

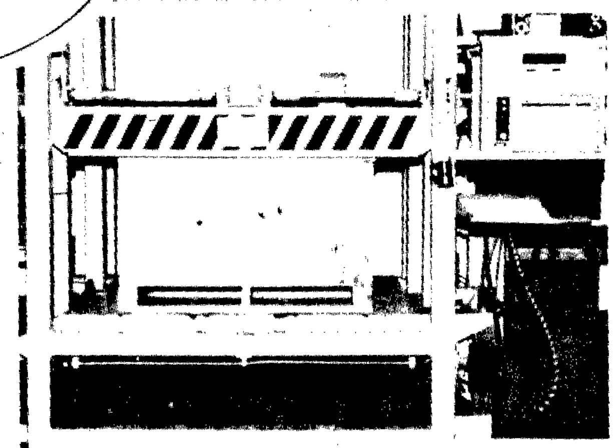


INCLINE IMPACT / RAIL HUMPING

INTERFACE OF
PALLETIZED AMMUNITION
WITH LOGISTICS
ENVIRONMENT



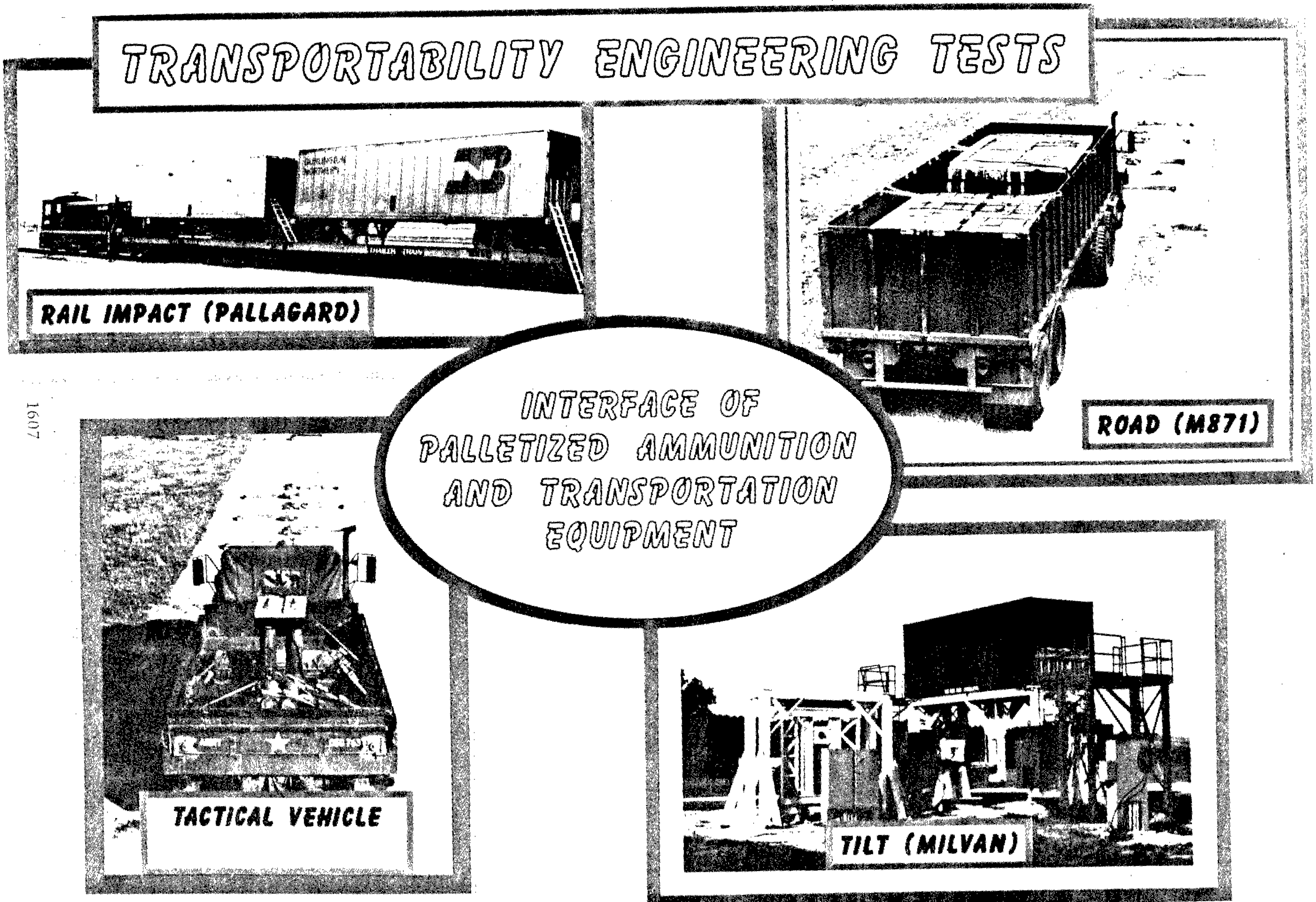
VIBRATION / RAIL & ROAD



STORAGE / STACKING

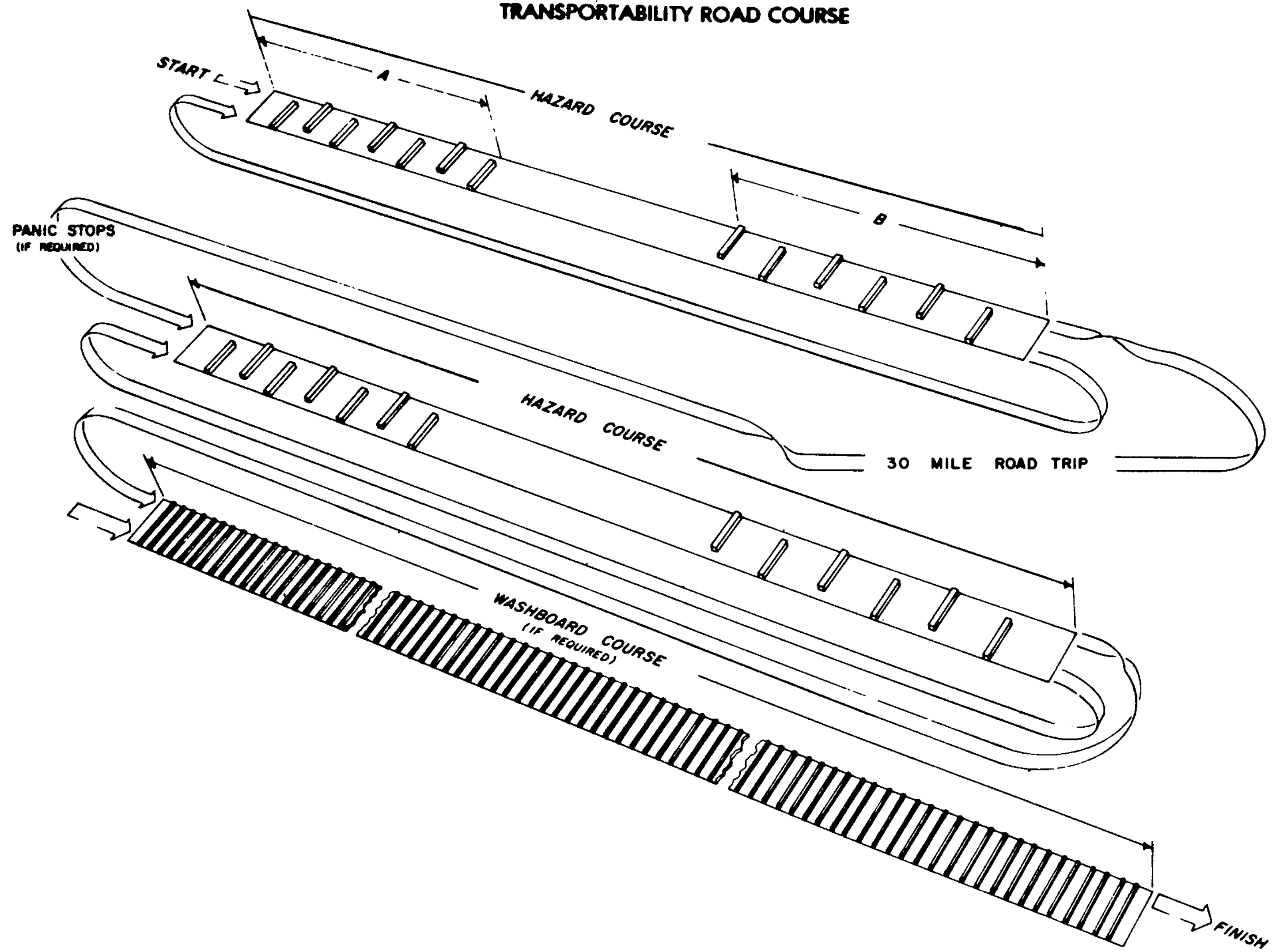
TRANSPORTABILITY TESTS REQUIRED

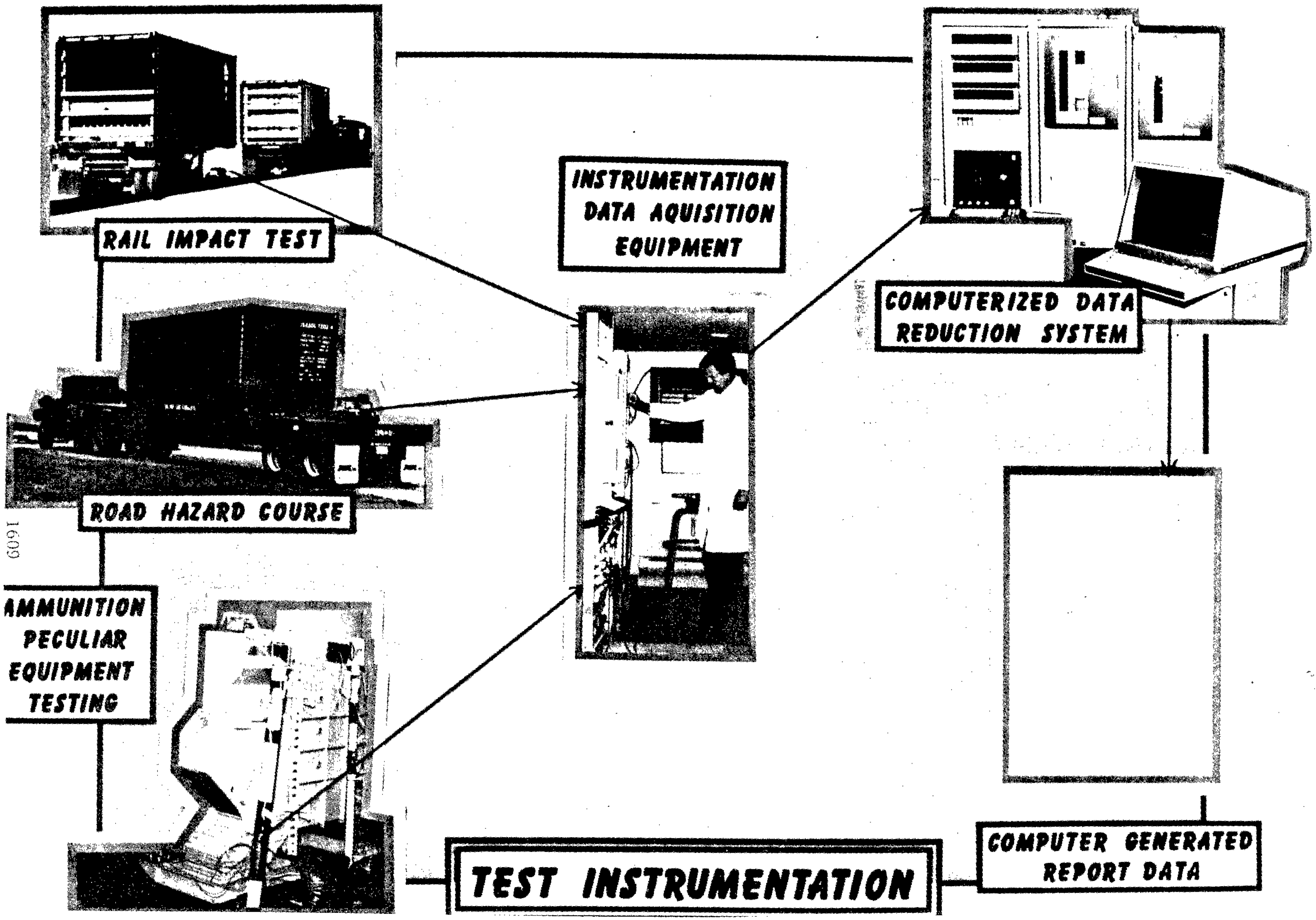
TESTS	REGULATORY APPROVAL
● RAIL IMPACT	
— BOXCAR, FLATCAR, TRAILER VAN	(AAR-BOE)
— INTERMODAL CONTAINER	(AAR-BOE & USCG)
● ROAD	
— TRAILER VAN, FLATBED, DROMEDARY	(AAR-BOE)
— INTERMODAL CONTAINER	(AAR-BOE & USCG)
● TILT	
— INTERMODAL CONTAINER 80° TILT TEST	(USCG)
— BREAKBULK & INTERMODAL CONTAINER STS	(UNDER DEVELOPMENT)

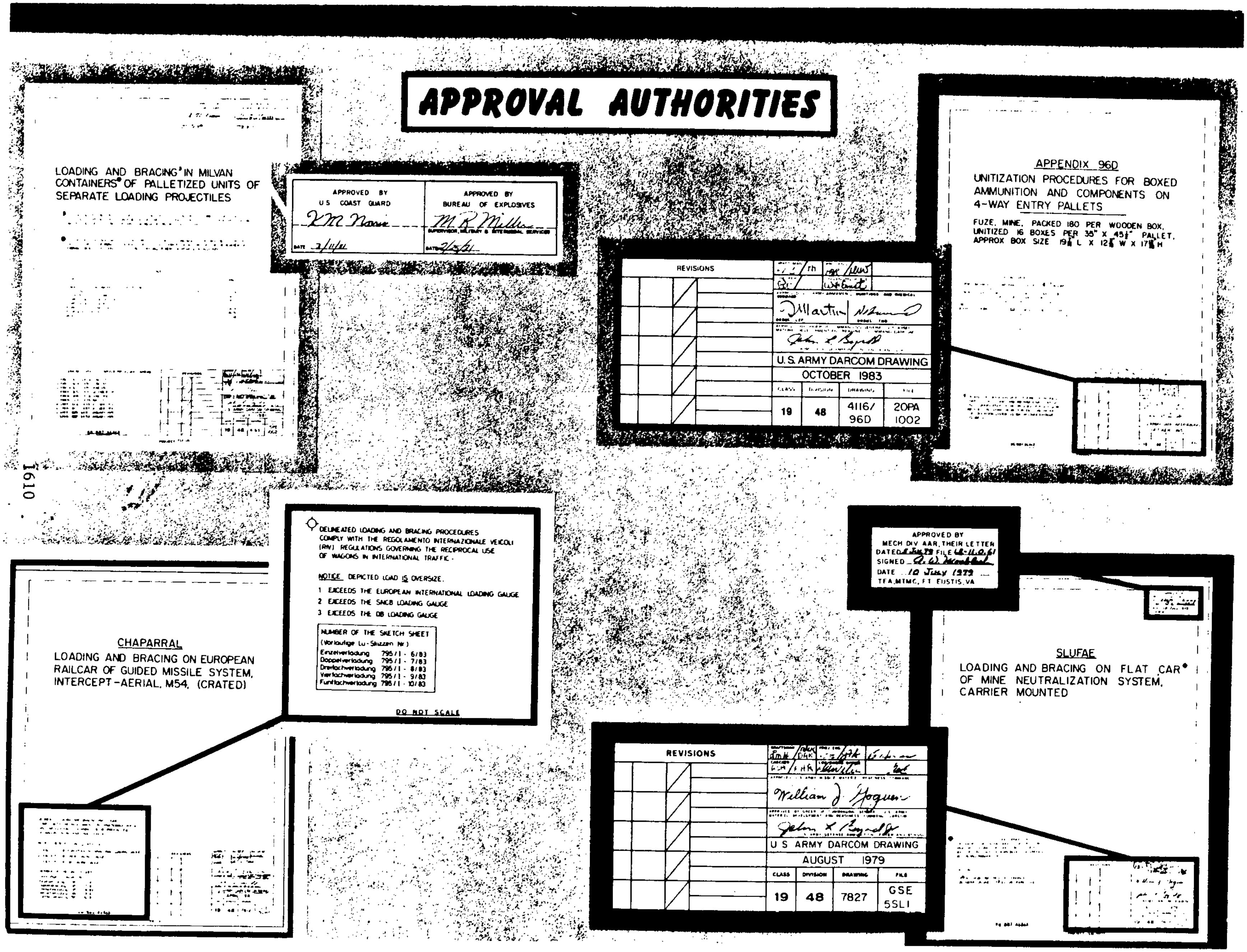

TRANSPORTABILITY ENGINEERING TESTS
RAIL IMPACT (PALLAGARD)
ROAD (M871)
INTERFACE OF
PALLETIZED AMMUNITION
AND TRANSPORTATION
EQUIPMENT
TACTICAL VEHICLE
TILT (MILVAN)

US ARMY DEFENSE AMMUNITION CENTER AND SCHOOL

TRANSPORTABILITY ROAD COURSE




RAIL IMPACT TEST
ROAD HAZARD COURSE
AMMUNITION PECULIAR EQUIPMENT TESTING
INSTRUMENTATION DATA AQUISITION EQUIPMENT
COMPUTERIZED DATA REDUCTION SYSTEM
COMPUTER GENERATED REPORT DATA
TEST INSTRUMENTATION

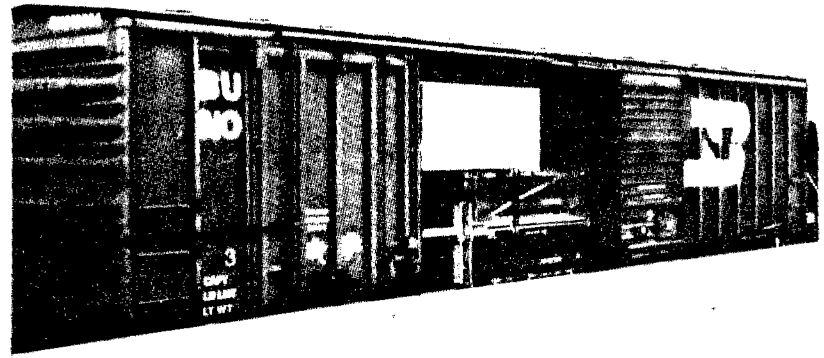


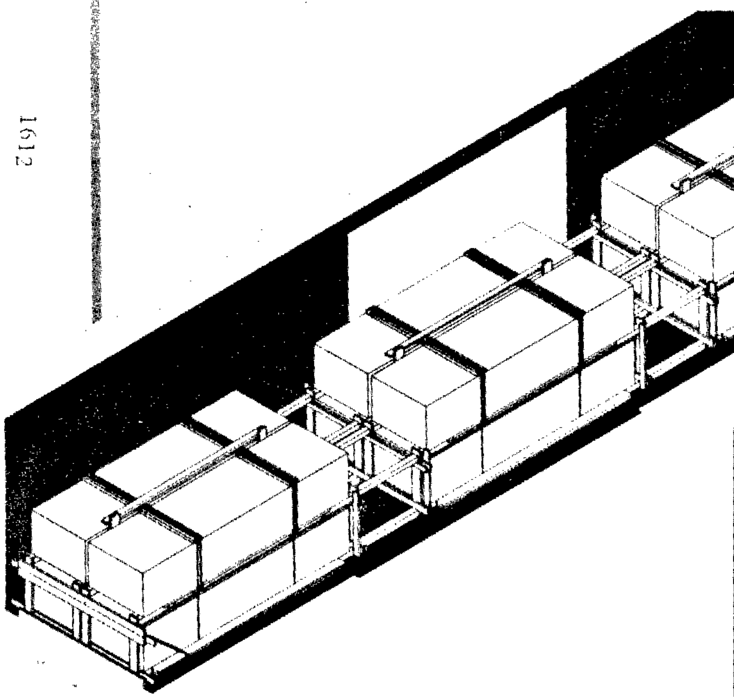
APPROVAL AUTHORITIES
LOADING AND BRACING IN MILVAN CONTAINERS OF PALLETIZED UNITS OF SEPARATE LOADING PROJECTILES
APPROVED BY U S COAST GUARD
APPROVED BY BUREAU OF EXPLOSIVES
APPENDIX 96D
UNITIZATION PROCEDURES FOR BOXED AMMUNITION AND COMPONENTS ON 4-WAY ENTRY PALLETS
REVISIONS
U.S. ARMY DARCOM DRAWING
OCTOBER 1983
19
48
4116/ 96D
20PA 1002
DELINEATED LOADING AND BRACING PROCEDURES COMPLY WITH THE REGOLAMENTO INTERNAZIONALE VEICOLI (RIV) REGULATIONS GOVERNING THE RECIPROCAL USE OF WAGONS IN INTERNATIONAL TRAFFIC.
NOTICE: DEPICTED LOAD IS OVERSIZE.
1 EXCEEDS THE EUROPEAN INTERNATIONAL LOADING GAUGE
2 EXCEEDS THE SNCB LOADING GAUGE
3 EXCEEDS THE DB LOADING GAUGE
NUMBER OF THE SKETCH SHEET
(Vorlaufige Lu-Skizzen Nr)
Einzelverladung 795/1 - 6/83
Doppelverladung 795/1 - 7/83
Dreifachverladung 795/1 - 8/83
Vierfachverladung 795/1 - 9/83
Funffachverladung 795/1 - 10/83
DO NOT SCALE
CHAPARRAL
LOADING AND BRACING ON EUROPEAN RAILCAR OF GUIDED MISSILE SYSTEM, INTERCEPT-AERIAL, M54, (CRATED)
APPROVED BY
MECH DIV AAR, THEIR LETTER
SIGNED
DATE 10 JULY 1979
TEA, MTMC, FT EUSTIS, VA
SLUFAE
LOADING AND BRACING ON FLAT CAR OF MINE NEUTRALIZATION SYSTEM, CARRIER MOUNTED
REVISIONS
U S ARMY DARCOM DRAWING
AUGUST 1979
CLASS
DIVISION
DRAWING
FILE
19
48
7827
GSE 5SL1

SURFACE TRANSPORTATION

- RAIL
  - CONVENTIONAL BOXCAR
  - MECHANICAL BOXCAR
  - FLAT CARS
  - GONDOLA CARS
  - C/TOFC
- MOTOR CARRIER
  - VAN TRAILERS
  - FLAT BED TRAILERS
  - DROP FRAME TRAILERS
  - DROMEDARY
- SHIP
  - BREAKBULK
- TACTICAL VEHICLE
  - CARGO TRUCKS
  - DUMP TRUCKS
  - CARGO TRAILERS
  - S & P TRAILERS
  - PERSONNEL CARRIERS
  - POLE TRAILERS
  - CARGO CARRIER (TRACK)
  - GOER
  - GAMMA GOAT
- INTERMODAL CONTAINERS
  - MILVAN
  - COMMERCIAL

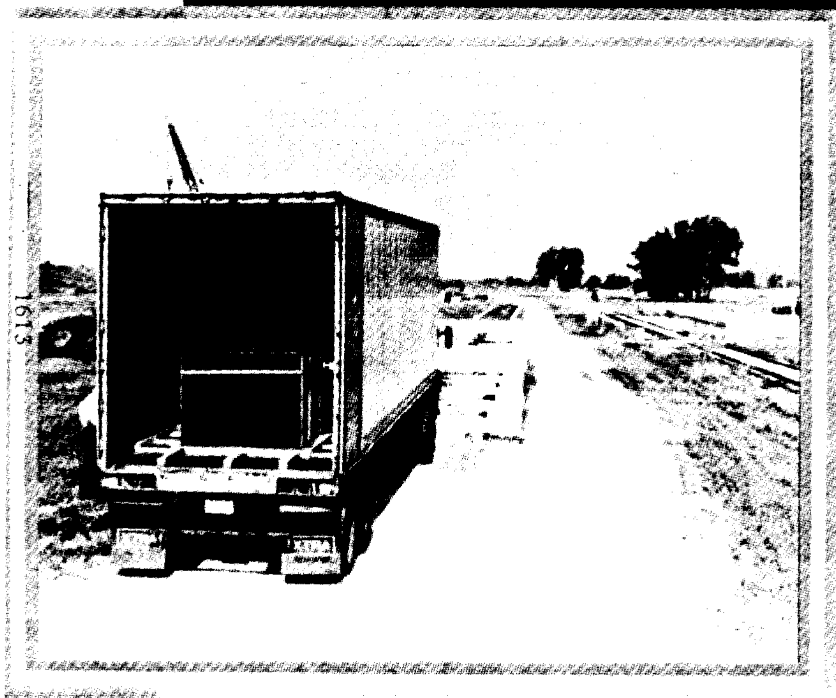
OUTLOADING - BOXCAR

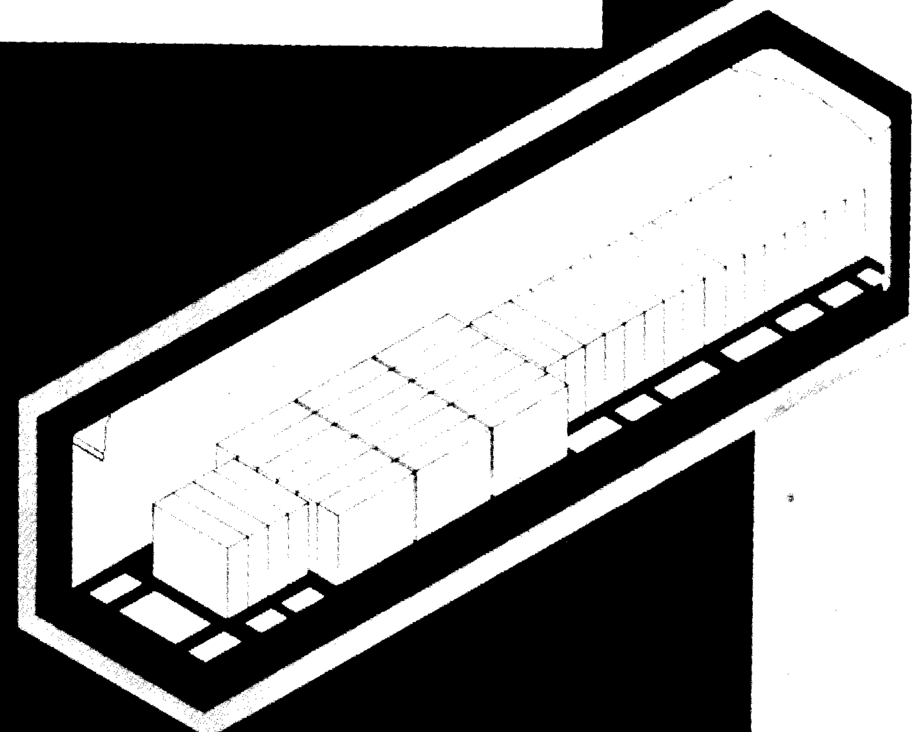




MULTIPLE LAUNCH ROCKET SYSTEM (MLRS), LAUNCH PODS/CONTAINERS

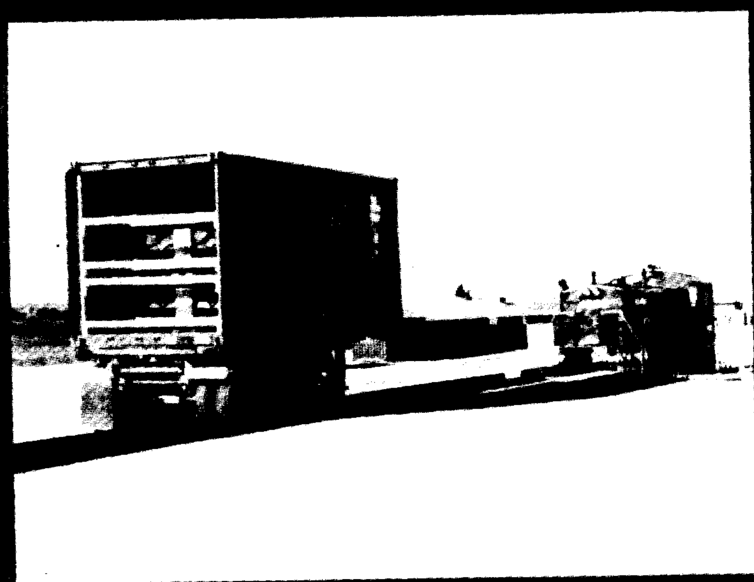
OUTLOADING - COMMERCIAL TRUCK

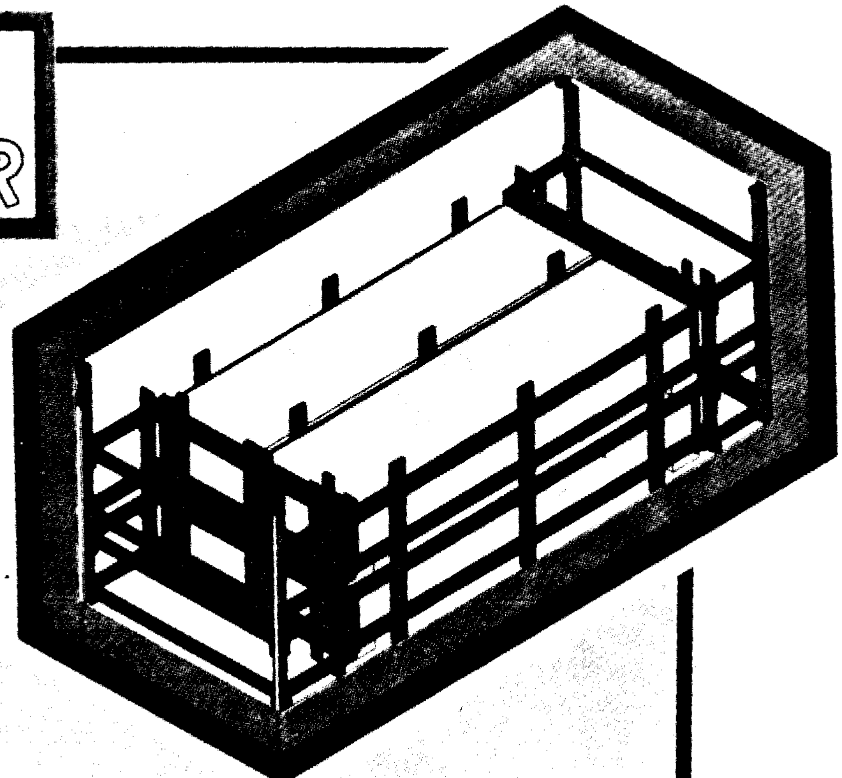




30MM AMMUNITION IN CNU 309/E CONTAINERS

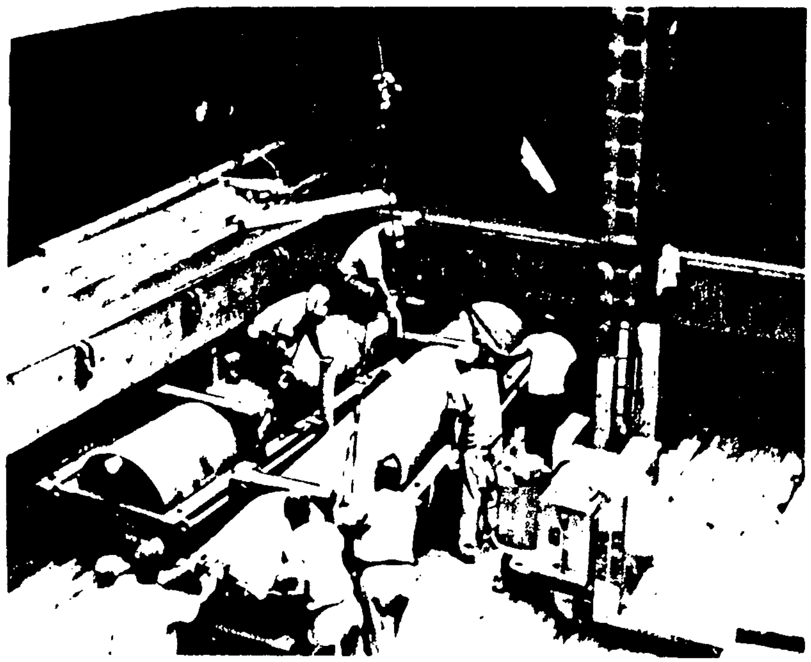
OUTLOADING - COMMERCIAL CONTAINER

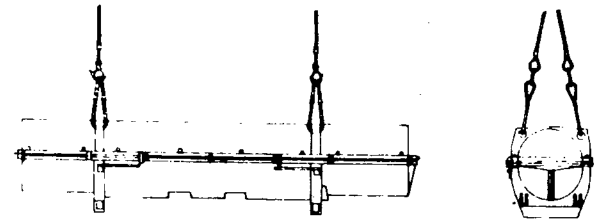


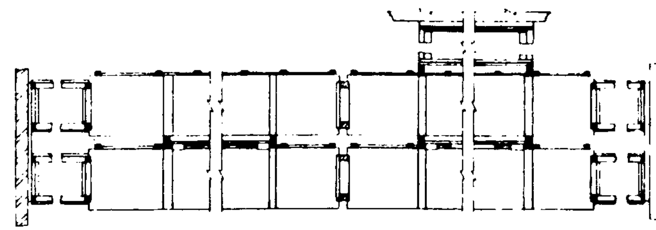


MULTIPLE LAUNCH ROCKET SYSTEM (MLRS), LAUNCH PODS/CONTAINERS

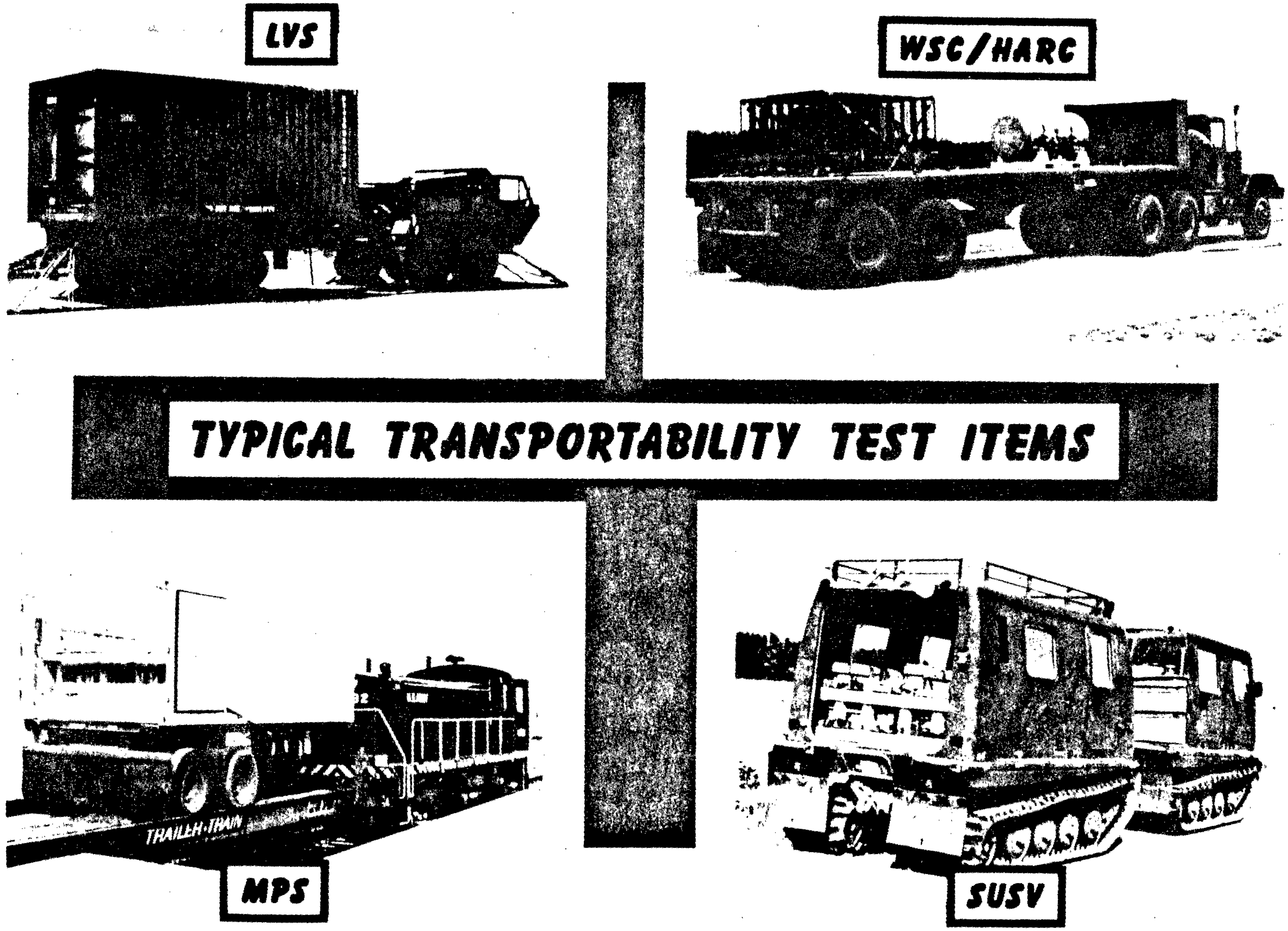
SHIPLOADING - BREAKBULK SHIP

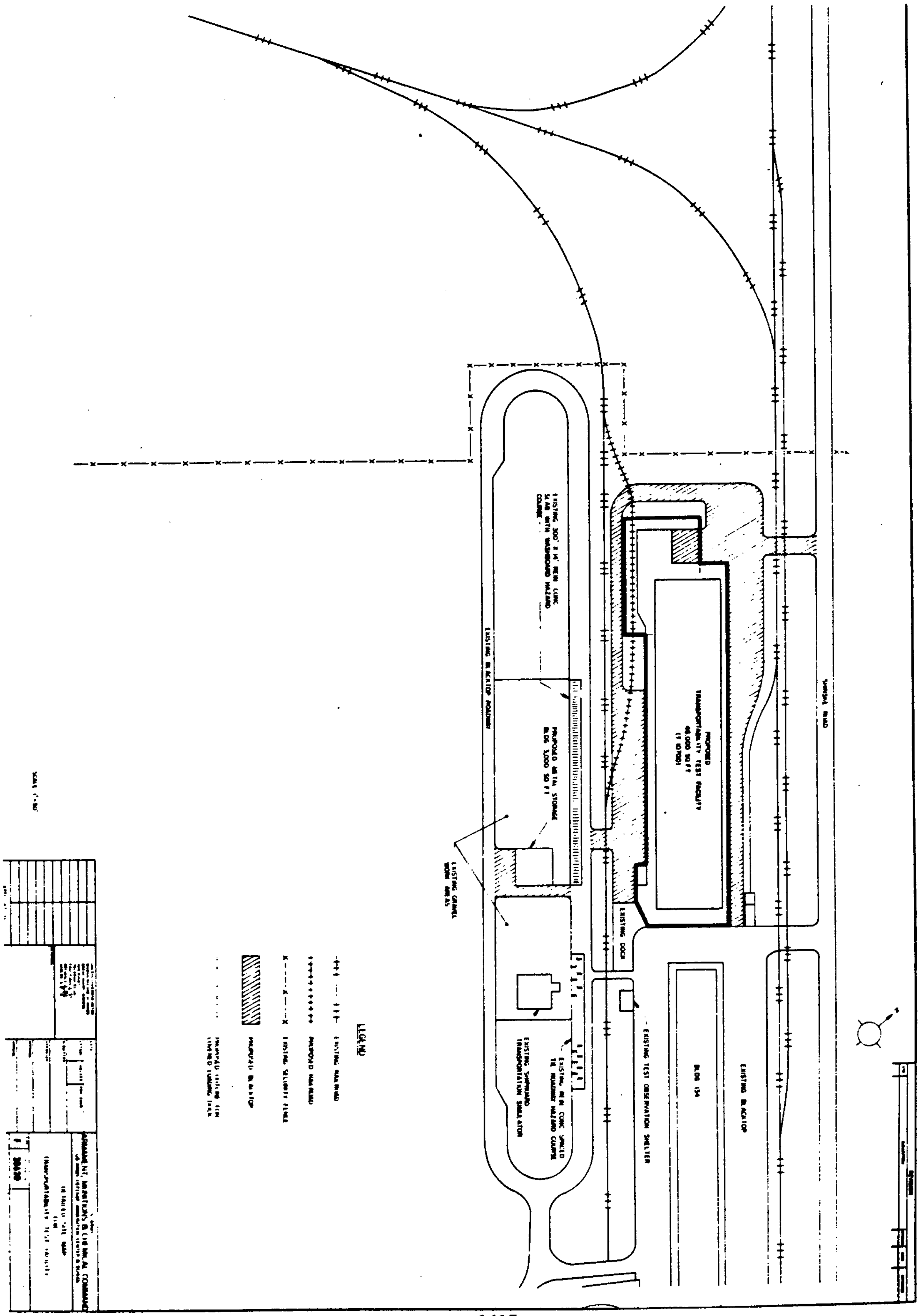






SERGEANT MISSILE ROCKET
MOTOR IN XM419 CONTAINER


TYPICAL TRANSPORTABILITY TEST ITEMS
LVS
WSC/HARC
MPS
THAILER-TRAIN
SUSV


LEGEND
EXISTING RAILROAD
PROPOSED RAILROAD
EXISTING SECURITY FENCE
PROPOSED BLACKTOP
EXISTING BLACKTOP ROADWAY
PROPOSED METAL STORAGE BLDG 3,000 SQ FT
EXISTING GRAVEL WORK AREAS
EXISTING DOCK
EXISTING TEST OBSERVATION SHELTER
EXISTING BLACKTOP
BLDG 134
PROPOSED TRANSPORTABILITY TEST FACILITY

HASTINGS IGLOO HAZARDS TESTS FOR
SMALL EXPLOSIVE CHARGES

H.J. Reeves
W.T. Robinson
US Army Ballistic Research Laboratory
Vulnerability/Lethality Division
Aberdeen Proving Ground, Maryland 21005

ABSTRACT

Full-scale field tests have been conducted to characterize the hazards to an exposed site when limited quantities of bulk explosives are positioned inside igloo magazines and statically detonated. Specific test objectives were to (1) determine the explosive quantity which, when detonated inside a standard-size, earth-covered magazine, produces no significant external effect; and (2) evaluate the dispersal of structure debris and measure external air blast for the range of explosive quantities from that marginally contained, up to 68 Kg (150 lb).

Test results in the form of overall structural response, air blast measurements, and hazardous fragment distributions are provided for selected explosive charge weights from 5.4 Kg (12 lb) to 68 Kg (150 lb).

INTRODUCTION

In 1979, the US Army Ballistic Research Laboratory (BRL) conducted a series of full-scale field tests* designed to characterize the hazards to an exposed site when either 68 Kg (150 lb) or 206 Kg (450 lb) TNT charges are positioned inside earth-covered reinforced concrete igloos and statically detonated. Test results took the form of air blast profiles and concrete fragment distributions in terms of densities, weights, and their locations relative to igloo orientation. These tests were conducted at the Navajo Depot Activity near Flagstaff, Arizona, where excess igloos, constructed in 1942 according to US Army specifications, were made available for destructive tests.

While the Flagstaff tests were conducted to support a hazards analysis at a particular site, they have also been used to support changes in the "Manual on NATO Safety Principles for the Storage of Ammunition and Explosives" that requires a minimum distance of 400 metres between inhabited buildings and igloos containing Hazard Division 1.1 ammunition or explosives. No minimum net explosive quantity is associated with this 400-metre restriction.

Approved for public release; distribution unlimited.

* *P. Howe, H. Reeves, and O. Lyman, "An Approach to Munitions Storage Applicable to the McNair Compound of the Berlin Brigade," US Army Ballistic Research Laboratory Special Report ARBRL-SP-00013, September 1979. ADC019277L*

The conclusions reached in the Flagstaff tests were:

1. The 400-metre minimum distance requirement between inhabited buildings and igloos containing Hazard Division 1.1 ammunition or explosives is excessive for small explosive weights. This is true for both fragment and peak overpressure hazards.

2. The use of a barricade in front of the headwall and a re-design of the vent stack at the rear of the igloo would have reduced the density of hazardous fragments to an insignificant level.

3. The peak overpressure and fragment hazards to the sides and rear of earth-covered igloos are significantly less than those to the front for relatively small explosive weights. These directional effects should be considered when establishing minimum distance requirements.

The Flagstaff tests have been supplemented with additional full-scale tests designed to (1) determine the explosive quantity which, when detonated inside a standard-size, earth-covered igloo, produces no significant external effect; and (2) evaluate the concrete fragment and external air blast hazards for a range of explosive quantities from that marginally contained, up to 68 Kg (150 lb).

All tests were sponsored by the Department of Defense Explosive Safety Board.

A description of these tests, test results, and analysis are presented in the following sections.

DESCRIPTION OF TESTS

All tests were conducted at the Nebraska State National Guard Weekend Training Site near Hastings, Nebraska, where a total of twelve excess igloo magazines were made available for destructive tests in support of this effort. This site is part of an abandoned Navy Ammunition Depot that was constructed during WW II. All of the igloos exhibited structural failures in the form of hairline cracks in the sidewalls, arch crest, backwall, and headwall. The igloos were constructed according to US Navy specifications and were designed to be earth-covered to a depth of at least 0.6 m (2 ft). Erosion of the earth-cover was observed in many cases due to a lack of maintenance. All of the magazines were weed-covered up to a height of 0.9 m (3 ft). The magazine headwalls faced an earth-backed concrete blast shield. The distance between the vertical headwalls and the blast shields varied between 3.7 m (12 ft) at the base to 3.7 m (15 ft) at the top (see Figures 1 through 3).

Pre-test site preparation included cutting the grass in front of the magazines out to a distance of 150 m (500 ft). The width of this cleared recovery area varied due to the presence of an elevated access road on the right side of the igloos (see Figure 4). The grass was cut out to the road on the right side. The cleared area on the left side of the igloos was essentially infinite. These recovery areas were searched after each test and concrete fragments weighing at least 0.18 Kg (0.4 lb) were catalogued in terms of numbers per discrete weight groups and their locations relative to the front of the igloo. A

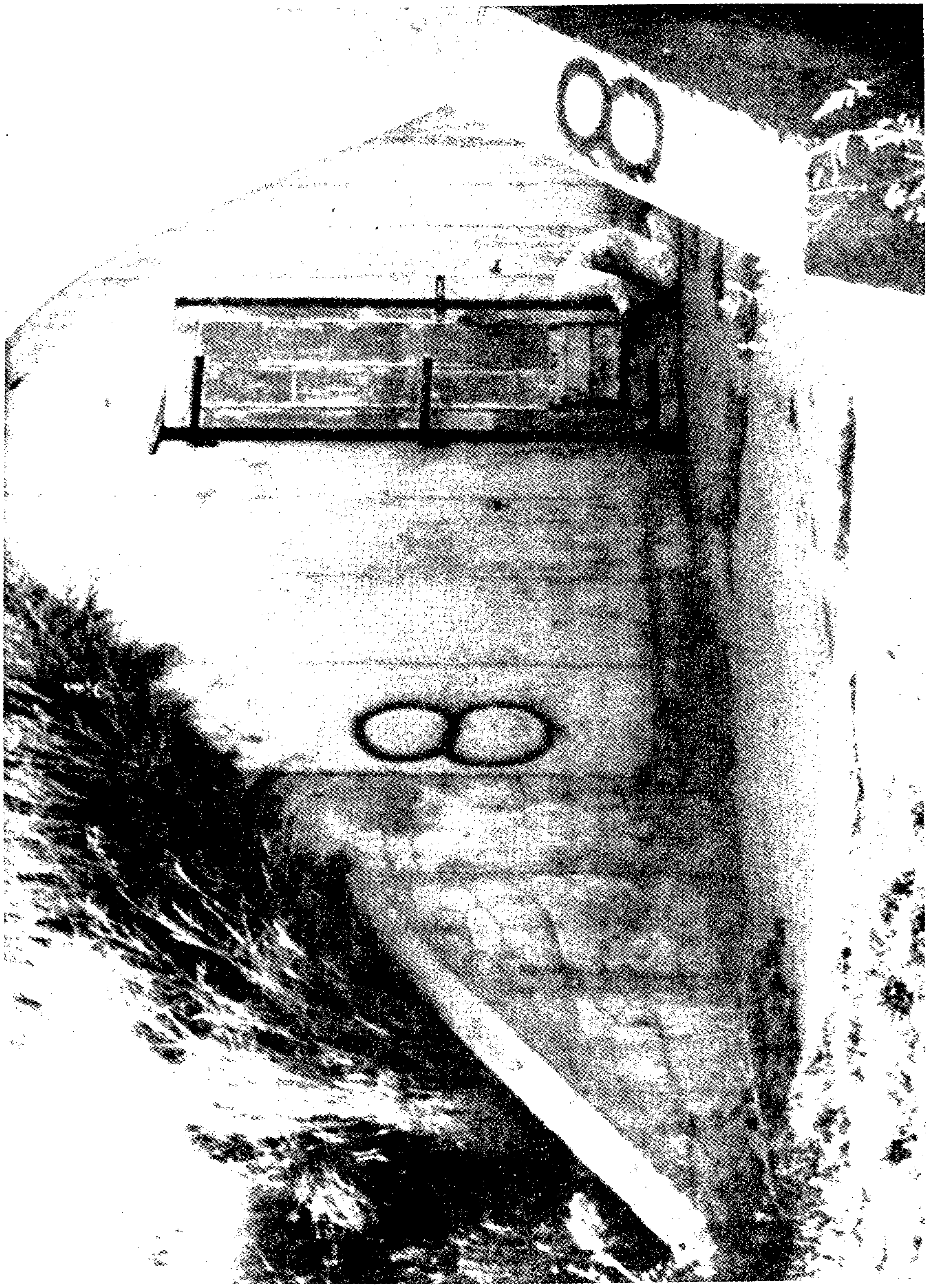


Figure 1. Oblique View of Igloo Magazine with Blast Shield.

Figure 2. Side View of Igloo Magazine Headwall, Blast Shield and Access Road.

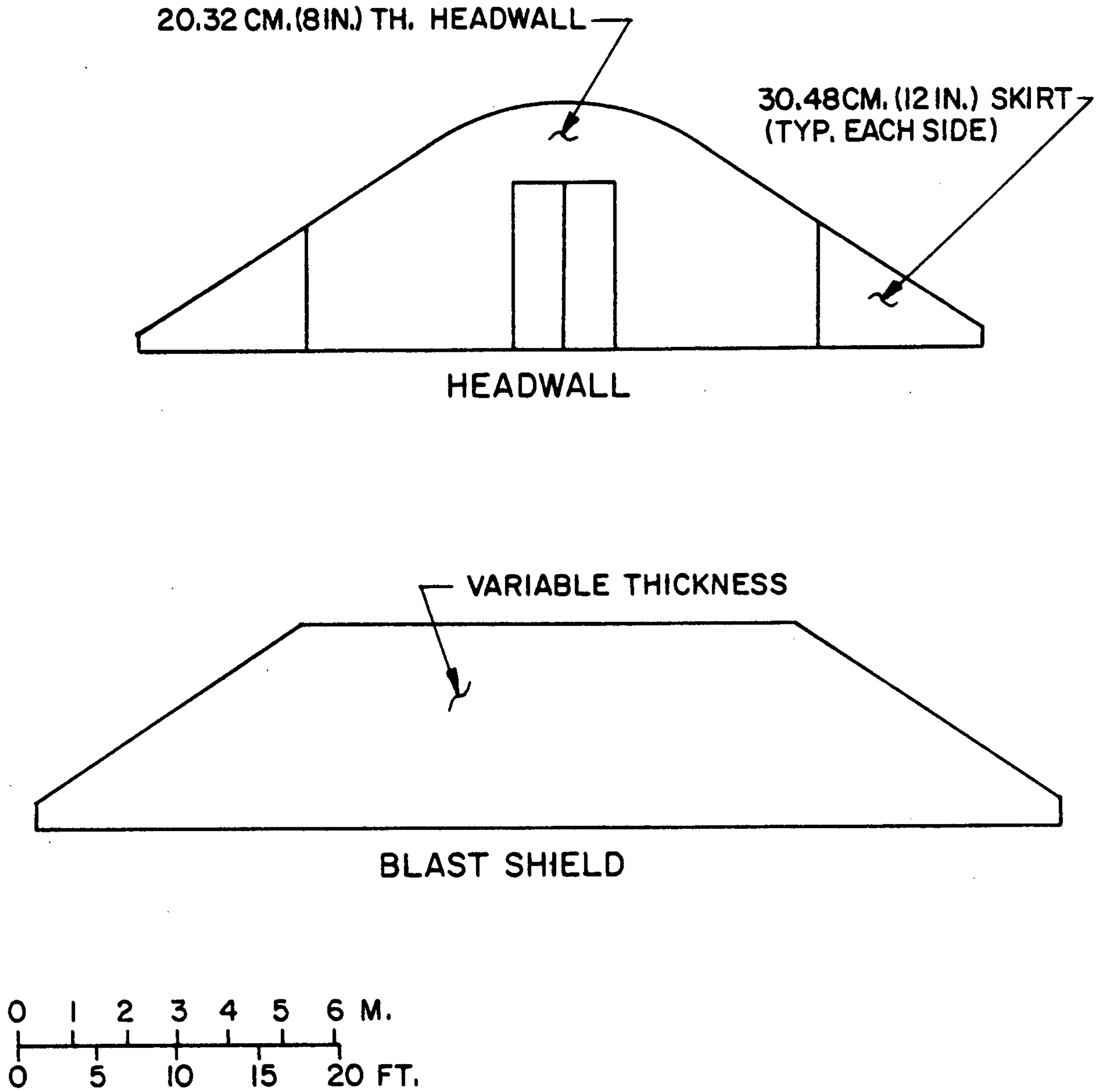


Figure 3. Schematic Drawing of Igloo Magazine and Blast Shield.

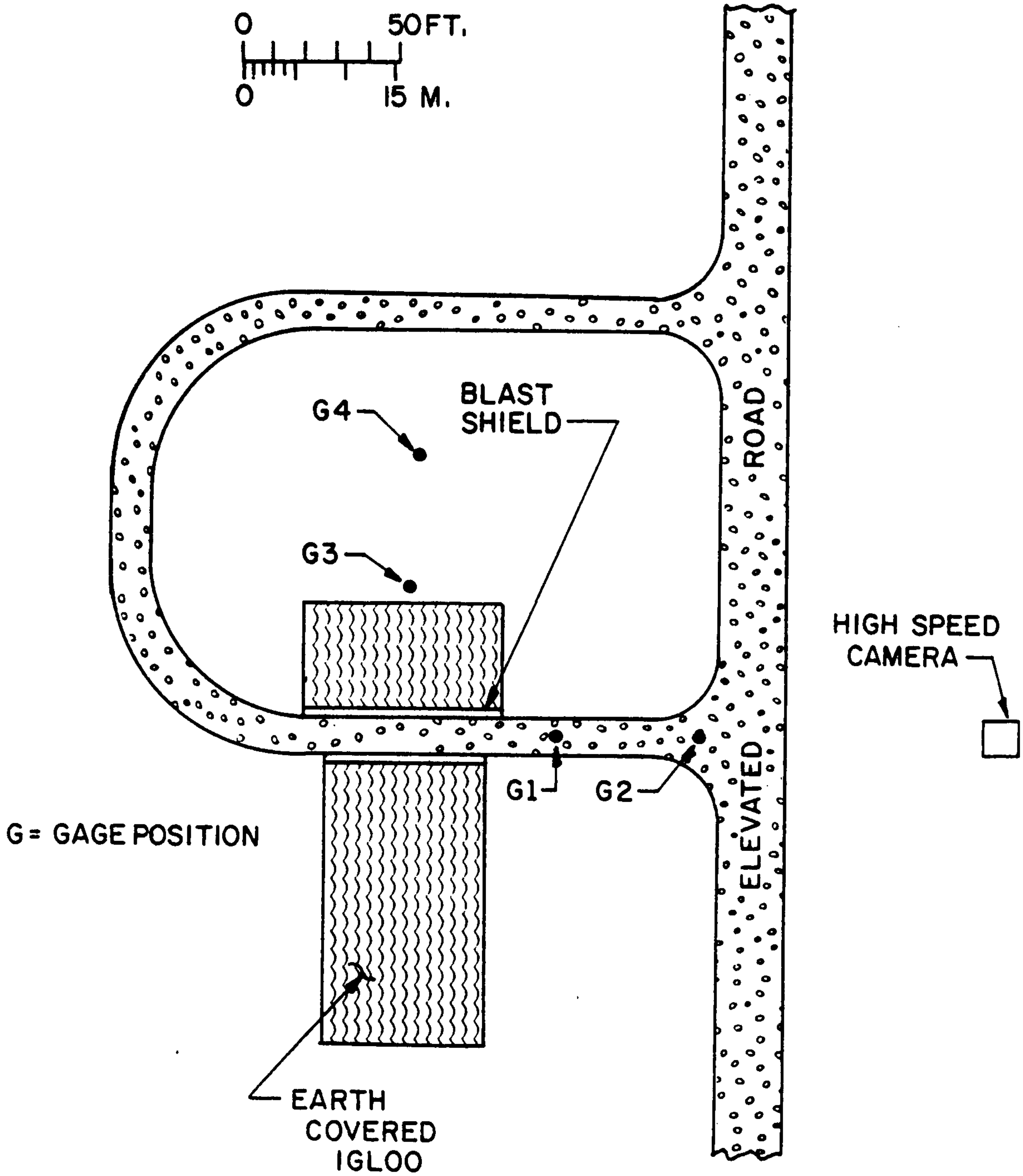


Figure 4. Test Layout Showing Location of Igloo, Blast Shield, Roads and Instrumentation.

postage scale was used to establish fragment weights up to 0.9 Kg (2 lb). The weights of heavier fragments were estimated.

Two high-speed (500 fps) 16-mm cameras were positioned to the side of the headwalls to monitor initial headwall fragment velocities. Air blast parameters were monitored by pressure transducers, flush mounted, via teflon collars, to lead blocks positioned to the sides and fronts of the igloos. A cleared path from the headwall to the pressure transducers was prepared using a front-end loader to remove vegetation and level the ground (see Figure 5). The data-gathering instrumentation system is shown in Figure 6.

Standard 3.36 Kg (8 lb) blocks of TNT with a small C4 booster charge, were positioned inside the igloos and statically detonated using long lengths of mild detonating fuze activated with electrically sensitive detonators. The position of the TNT charge was deliberately varied, in those tests involving 5.44 Kg (12 lb) charges, to determine the influence of charge location on incipient headwall failure.

RESULTS AND OBSERVATIONS

The tests results are presented in three categories: structural response, external air blast, and hazardous fragment distributions; and each are discussed in the following sections.

STRUCTURAL RESPONSE

The test results in terms of structural response are presented in Table 1 and Figures 7 through 15.

While the results of Tests 3, 4, and 5 (5.4 Kg charge positioned 4 metres from the headwall) are observably different, the differences in terms of structural response are not significant and could be explained in terms of variations in the structural integrity of these 40-year old magazines.

The complete headwall failures observed in Tests 6 and 8, where the 5.4 Kg charge was positioned 4 metres from the rear wall, were different in terms of structural response from the results of Tests 3, 4, and 5. However, these differences had little or no effect in defining hazardous distances. When the headwalls failed in Tests 6 and 8, they fractured into large pieces that were recovered in front of the blast shield (see Figures 12 and 15). The real hazards in the 5.4 Kg test series were the doors that were thrown clear of the area between the headwall and the blast shield after bouncing off the blast shield.

The inconsistency observed between the results of Tests 1, 2, and 7, where a 7.3 Kg charge produced more severe structural damage than either an 11 Kg or 18 Kg charge, can only be explained in terms of unobservable differences in the condition of the magazines before testing.

Figure 5. Rear View of Blast Shield Showing Cleared Path for Pressure Transducers.

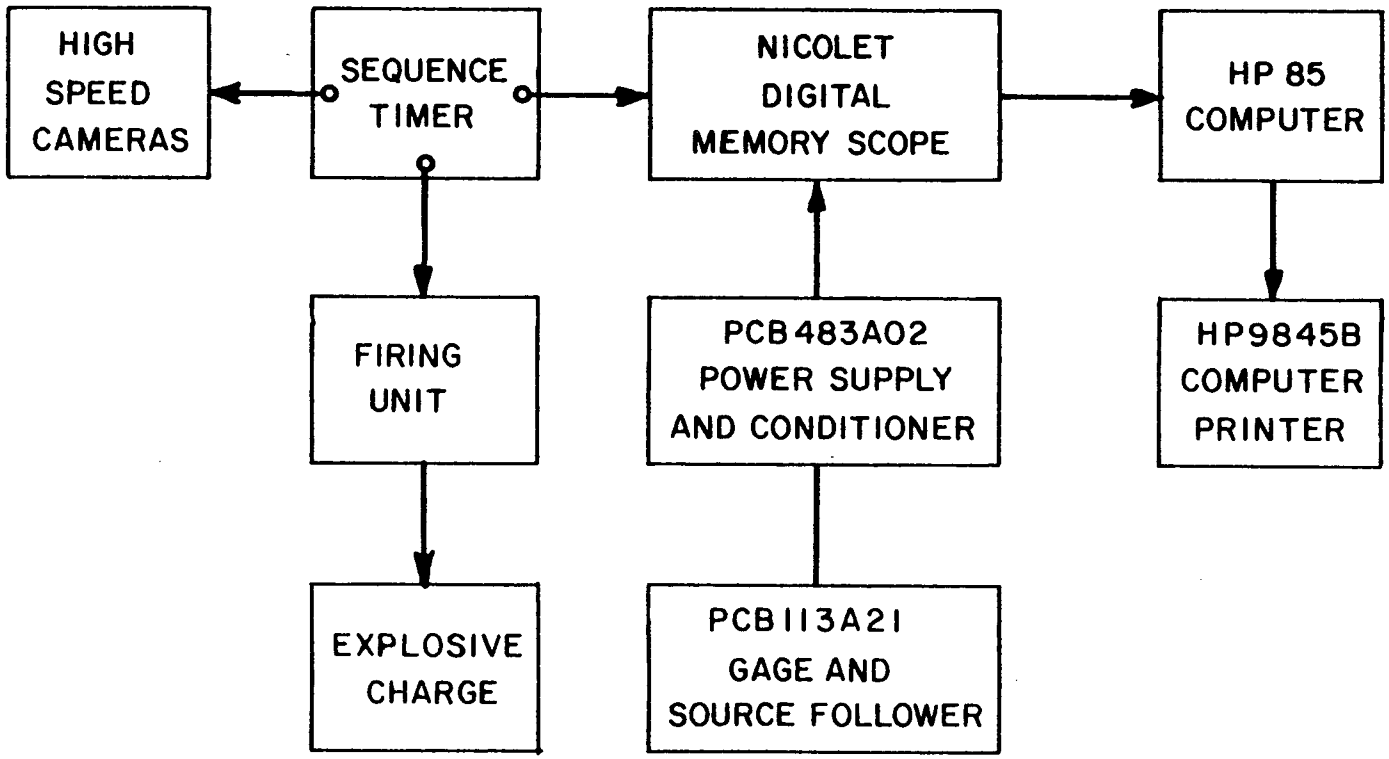


Figure 6. Instrumentation System

TABLE 1. TEST RESULTS - EXPLOSIVE CHARGES POSITIONED INSIDE EARTH-COVERED IGLOO MAGAZINES

Test No.	Charge Wgt.	Charge Position	Remarks
1	18 Kg (40 lb)	4 m (13 ft) from headwall	Headwall failed. Approximately 50% of the arch crest and 35% of the sidewalls in the front and rear of the igloo destroyed. All debris from arch crest and sidewall recovered on the floor of the igloo. Large center section of the igloo remained standing. Some debris from headwall scattered along entrance roadway after bouncing off blast shield. One large piece (5.4 Kg) of concrete from headwall cleared blast shield and recovered 40 metres in front of the headwall. Parts of terra cotta vent stack scattered up to 10 metres from the rear of the magazine. The wood-core and metal sheathed doors were destroyed and recovered between headwall and blast shield (see Figure 7).
2	11 Kg (24 lb)	4 m (13 ft) from headwall	Headwall failed. Arch crest cracked and displaced. Forward section of left sidewall failed (see Figure 8). A total of nine concrete fragments weighed in excess of 4 Kg. The remainder of the fragments weighed between 0.5 Kg and 2.0 Kg. A large piece of the door (9 Kg) recovered 30 metres to the right and 7 metres behind the headwall.
3	5.4 Kg (12 lb)	4 m (13 ft) from headwall	There was a large crack in the face of the headwall. The headwall was still in one piece and standing in place (see Figure 9). The right side door recovered 15 metres from the center of the headwall on the right side. The left side door recovered 30 metres from the center of the headwall on the left side.

TABLE 1. TEST RESULTS - EXPLOSIVE CHARGES POSITIONED INSIDE EARTH-COVERED IGLOO MAGAZINES (CONTINUED)

Test No.	Charge Wgt.	Charge Position	Remarks
4	5.4 Kg (12 lb)	4 m (13 ft) from headwall	The headwall separated from the sidewall and exhibited several large cracks. The headwall was still standing and held together by rebar (see Figure 10). The right door recovered 24 metres from the center of the headwall. The left door recovered 49 metres from the center of the headwall on the left side.
5	5.4 Kg (12 lb)	4 m (13 ft) from headwall	The headwall failed and separated into several large pieces, however, the headwall held in place by rebar (see Figure 11). The left door, almost intact, recovered 40 metres from the center of the headwall on the left side. The right door recovered in one piece 56 metres on the right side.
6	5.4 Kg (12 lb)	4 m (13 ft) from rear wall	The headwall failed completely, separated from the sidewall, and fractured into several large pieces. The left door recovered 31 metres to the side and 15 metr s to the rear of the headwall. The right door recovered 27 metres to the side and 1.8 metres to the rear of the headwall (see Figure 12).
7	7.3 Kg (16 lb)	4 m (13 ft) from headwall	A 6 metre (20 ft) long section of the right, rear sidewall remained standing. The remainder of sidewall and headwall was destroyed. A large piece of the left door recovered 37 metres to the left side of the igloo. A large section of the right door recovered 12 metres to the right side. Four large pieces of concrete, all approximately 9 Kg, recovered on the rear side of the blast shield earth fill (see Figure 13).

TABLE 1. TEST RESULTS - EXPLOSIVE CHARGES POSITIONED INSIDE EARTH-COVERED IGLOO MAGAZINES (CONTINUED)

Test No.	Charge Wgt.	Charge Position	Remarks
8	5.4 Kg (12 lb)	4 m (13 ft) from rear wall	Headwall failed and fractured into several large pieces. A large crack in arch crest entire length of the igloo. Several large cracks in the sidewall on each side. Further examination was not possible as igloo was in imminent danger of collapsing. Large pieces of right door recovered 30 metres to the side and 18 metres and 24 metres to the rear of the headwall. Large pieces of left door recovered 24 metres and 40 metres to the the side and 24 metres to the rear of the headwall. One other piece of left door recovered 61 metres from the headwall on the left side (see Figure 14 and 15).
9	45.4 Kg (100 lb)	Center of the igloo	The igloo was completely destroyed. Concrete fragments recovered out to a distance of 149 metres.
10	68 Kg (150 lb)	Center of the igloo	The igloo was completely destroyed. Concrete fragments recovered out to a distance of 244 metres.
11	36 Kg (80 lb)	Center of the Igloo	The igloo was completely destroyed. Concrete fragments recovered out to a distance of 143 metres.
12	27 Kg (60 lb)	Center of the igloo	The igloo was completely destroyed. Concrete fragments recovered out to a distance of 110 metres.

Figure 7. Test Results - Test No. 1, 18 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall.

Figure 8. Test Results - Test No. 2, 11 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall.

Figure 9. Test Results - Test No. 3, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall.

Figure 10. Test Results - Test No. 4, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall.

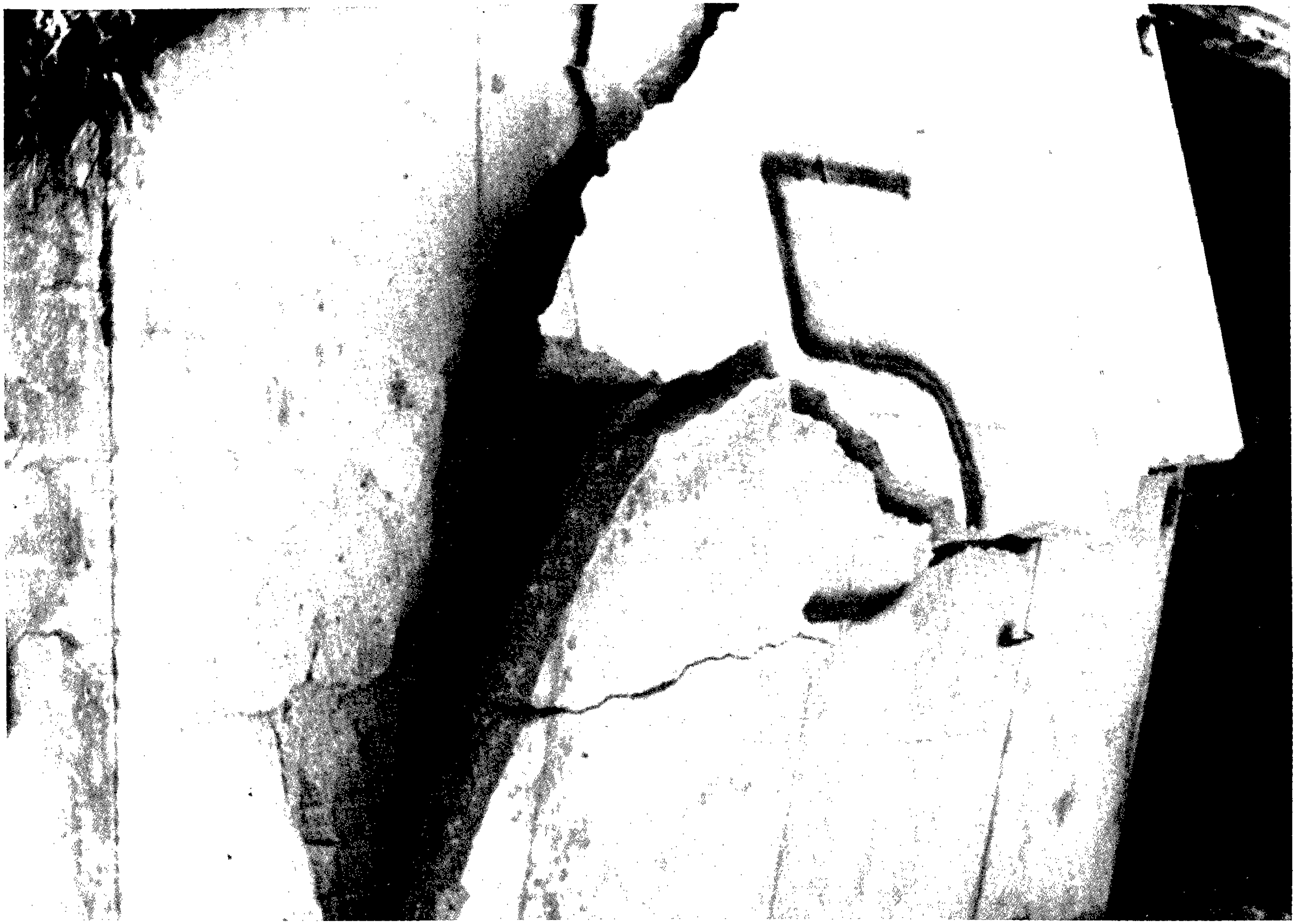


Figure 11. Test Results - Test No. 5, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall.

Figure 12. Test Results - Test No. 6, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Rear Wall.

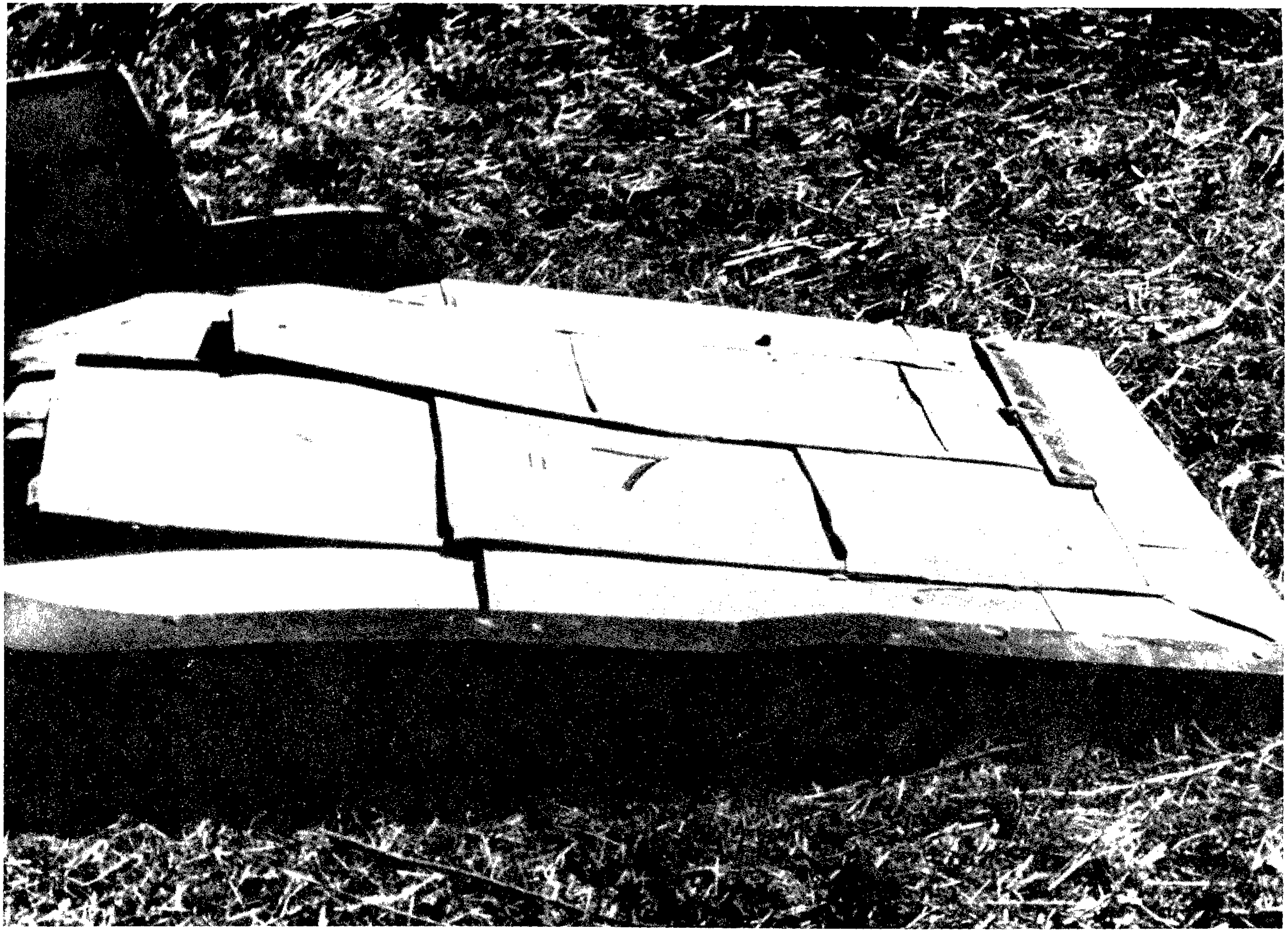


Figure 13. Test Results - Test No. 7, 7.3 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall.

Figure 14. Test Results - Test No. 8, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Rear Wall.

Figure 15. Test Results - Test No. 8, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Rear Wall.

EXTERNAL AIR BLAST MEASUREMENTS

Peak overpressure, impulse, and time-of-arrival measurements are presented in tabular form in Table 2. Instrumentation was not available for Tests 1, 9, and 10. Data for Test 3 was lost due to equipment malfunction.

There were no hazardous overpressures measured in any of these tests. While some of the pressure-time history records were difficult to read due to low pressure levels and non-classical shapes, they are mutually supporting.

It is of interest to note that the pressure-time histories recorded for explosive charge weights up to 10.9 Kg were apparently reflected shock pressure-time histories; i.e., the incident shock removed the doors allowing the shock wave that was reflected off the rear wall to escape unimpeded. The presence of the reflected shock wave was verified photographically and explains the apparent anomaly in the time-of-arrival measurements recorded in those tests where the 5.4 Kg charge was positioned near the rear wall. No reflected shock wave was observed in the 45.4 Kg and 68 Kg charge weight tests where the entire igloo was destroyed rapidly, allowing pressure to vent upward. The pressure-time histories recorded for these tests were from the incident wave.

HAZARDOUS FRAGMENT DISTRIBUTIONS

The results of the fragment collection effort for those tests with charge weights between 27 and 68 Kg, positioned in the center of the magazines, are presented in Table 3 in terms of hazardous fragment densities per 600 ft^2 for the discrete angular and distance increments.* These distributions were generated by averaging all the fragment data for a given test when fragment data from both the right and left side recovery areas were available. When fragment data from only one side was available, symmetry was assumed. These distributions do not reflect the uneven distribution observed in some of these tests where the number of fragments recovered on the left side of the recovery area was greater than those recovered on the right. These skewed distributions are assumed to be an anomaly.

Exponential density functions for these tests were generated using the density distributions in Table 3 to compare predicted and observed densities, per 600 ft^2, independent of angle; i.e., the highest density value for a given distance increment was used in the calculation (see Figures 16 through 19). Fragment density distributions at distances less than 53 metres were not used due to the masking effect of the blast shield.

**The origin of the coordinate system used in generating these distributions was the front of the igloo.*

TABLE 2. PEAK OVERPRESSURE, IMPULSE AND TIME-OF-ARRIVAL (TOA) FROM TNT CHARGES STATICALLY DETONATED INSIDE IGLOO MAGAZINES

TNT Charge Weight		Position[a]		Gage Position[b]		Pressure		Impulse		TOA
Kg	lb	m	ft	m	ft	psi	kPA	psi-msec	kPA-msec	msec
				24.3F	80	0.5	3.4	Lost		161
				27.4F	90	0.4	2.8	Lost		168
10.9	24	4	13	18.3S	60	0.76	5.2	3.75	25.9	160
				27.4S	90	0.55	3.8	2.59	17.9	167
				18.3F	60	1.0	6.9	9.85	67.9	69
45.4	100	12	40	27.4F	90	0.7	4.8	7.78	53.7	95
				15.2S	50	1.2	8.3	8.55	59.0	62
				27.4F	90	0.74	5.1	4.11	28.3	92
68.0	150	12	40	18.3F	60	1.41	9.7	13.46	92.8	66
				27.4F	90	1.23	8.5	9.94	68.6	92
				15.2S	50	1.53	10.6	8.83	60.9	60
				27.4F	90	1.07	7.4	7.21	49.7	86

[a] *Distance measured from the headwall to where the TNT charge was positioned inside the igloo.*

[b] *Distance measured from the center of the headwall to where the gage was positioned. F = in front of the headwall. S = to the side of the headwall.*

TABLE 2. PEAK OVERPRESSURE, IMPULSE AND TIME-OF-ARRIVAL (TOA) FROM TNT CHARGES STATICALLY DETONATED INSIDE IGLOO MAGAZINES (CONTINUED)

TNT Charge Weight		TNT Charge Position[a]		Gage Position[b]		Pressure		Impulse		TOA
Kg	lb	m	ft	m	ft	psi	kPA	psi-msec	kPA-msec	msec
5.4	12	4	13	18.3F	60	0.4	2.8	4.69	32.2	Lost
5.4	12	4	13	18.3F	60	0.62	4.3	4.83	33.3	147
				27.4F	90	0.46	3.2	3.27	22.6	172
				15.2S	50	0.67	4.6	5.52	38.1	132
				27.4S	90	0.34	2.3	3.06	21.0	168
5.4	12	20.4	67	18.3F	60	0.16	1.1	0.53	3.7	110
				27.4F	90	0.25	1.7	1.73		135
				15.2S	50	0.39	2.7	1.91	13.2	97
				27.4S	90	0.23	1.6	1.10	7.6	134
5.4	12	20.4	67	18.3F	60	0.36	2.5	2.87	19.6	114
				27.4F	90	0.33	2.3	1.05	7.2	139
				15.2F	50	0.69	4.8	2.37	16.3	100
				27.4S	90	0.27	1.9	1.05	7.2	135
7.3	16	4	13	18.3F	60	0.49	3.4	4.03	27.8	138
				27.4F	90	0.34	2.3	2.50	17.2	163
				15.2S	50	0.51	3.5	3.24	22.3	138
				27.4S	90	0.35	2.4	2.36	16.3	166

[a] *Distance measured from the headwall to where the TNT charge was positioned inside the igloo.*

[b] *Distance measured from the center of the headwall to where the gage was positioned. F = in front of the headwall. S = to the side of the headwall.*

TABLE 3. TEST RESULTS - HAZARDOUS FRAGMENT DENSITIES PER 600 FT^2 FOR DISCRETE ANGULAR AND DISTANCE INCREMENTS

Distance		27 Kg (60 lb) Test			36 Kg (80 lb) Test			45 Kg (100 lb) Test			68 Kg (150 lb) Test		
m	Ft.	0-5°	5-10°	10-45°	0-5°	5-10°	10-45°	0-5°	5-10°	10-45°	0-5°	5-10°	10-45°
31	100	6.3	4.7	9.0	0	0	2.8	0	0	3.5	3.1	2.4	3.8
38	125	24.3	21.9	26.8	0	0.6	2.1	0	2.4	3.1	0	3.0	6.1
46	150	19.9	10.0	7.1	10.0	10.5	3.8	23.8	18.8	9.3	21.9	12.5	9.5
53	175	40.4	25.0	23.2	28.6	16.8	4.6	16.8	15.8	8.5	10.2	5.9	3.2
61	200	19.4	12.7	6.3	20.4	13.2	4.2	3.0	8.0	6.9	19.1	12.5	6.4
69	225	18.0	9.7	4.7	15.5	10.7	7.0	0	5.8	1.4	3.9	3.8	2.6
76	250	20.7	13.3	3.1	18.4	10.9	2.9	20.8	15.0	4.1	1.2	1.2	1.1
84	275	10.4	6.3	1.8	4.1	3.1	1.2	2.0	4.1	2.1	7.2	6.2	1.6
91	300	2.0	1.5	0.3	11.4	6.6	2.4	3.8	3.6	1.1	5.8	4.8	1.8
99	325	1.8	2.2	1.1	0.9	1.3	1.9	3.6	3.1	0.9	4.5	2.9	0.8
107	350	1.6	0.8	0.6	2.4	1.6	3.2	0	0.4	0.7	4.8	4.6	2.3
114	375	1.5	0.8	0.2	3.0	1.5	0.8	0	1.1	2.5	9.9	5.5	1.3
122	400	0	0	0.8	5.6	3.2	1.5	0	0.7	0.6	4.2	3.0	1.0
130	425	1.4	0.7	0.1	0.7	0.7	0.1	0	0.7	1.2	4.7	2.7	0.7
137	450				1.3	0.8	0.3				3.2	1.8	0.6
145	475				1.2	0.6	0.2				2.4	2.0	0.4
152	500				2.8	1.7	0.7				2.3	1.7	1.1
160	525				1.1	0.5	0.1				3.2	2.0	0.8
168	550										5.0	2.6	0.7
175	575										0	0.1	0.2
183	600										1.0	0.7	0.7
191	625										2.2	1.3	0.7
198	650										2.2	1.4	0.3
206	675										0.4	0.3	0.4
213	700										0.4	0.2	0.1
221	725										0	0	0.2

NOTE: Explosive charges were positioned in the center of the magazines. Angular deviations are half angles.

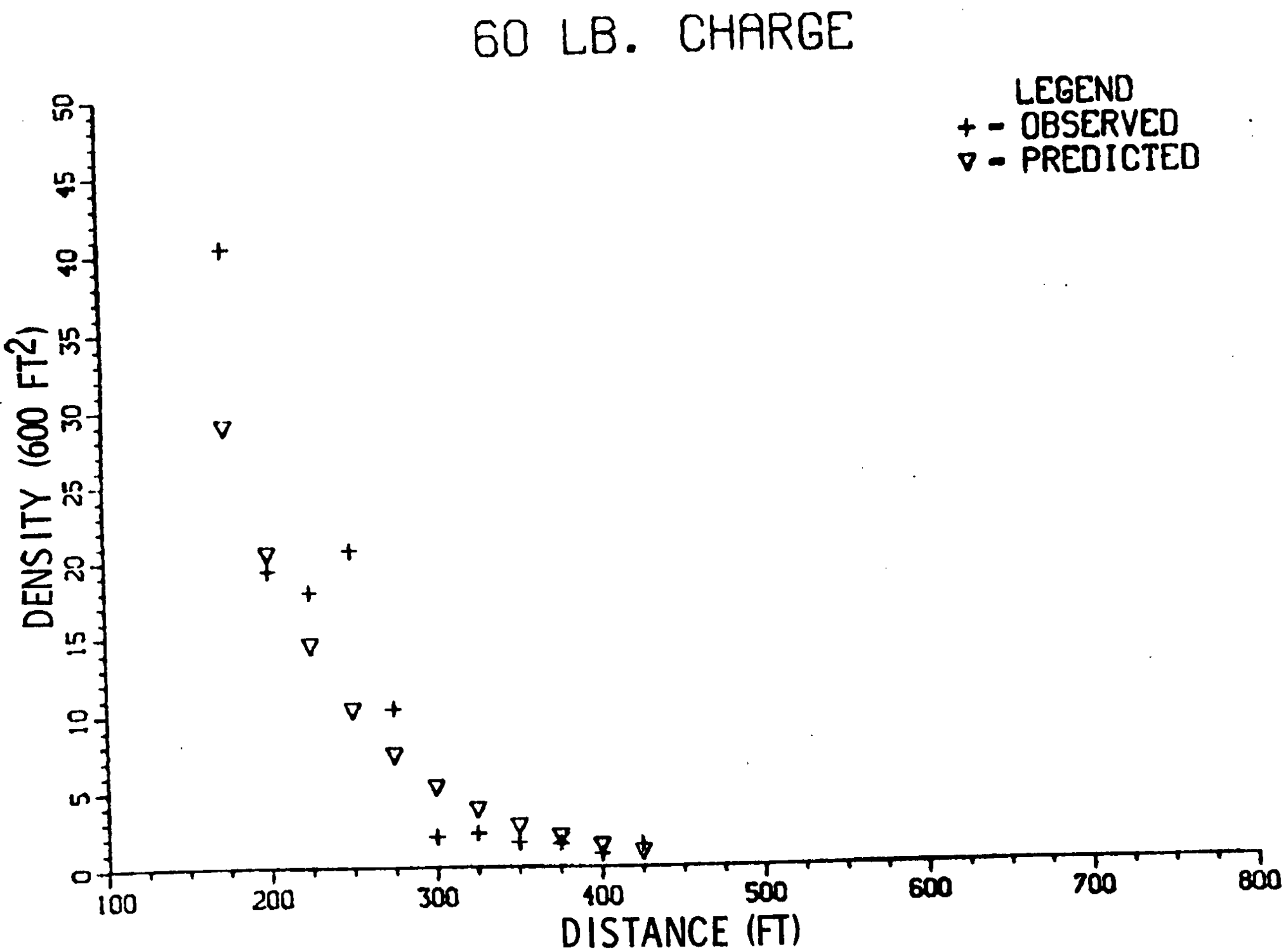


Figure 16. Hazardous Fragment Densities (600 ft^2) Versus Distance in Front of an Igloo Magazine-27 Kg TNT Charge Positioned in the Center of Igloo Statically Detonated.

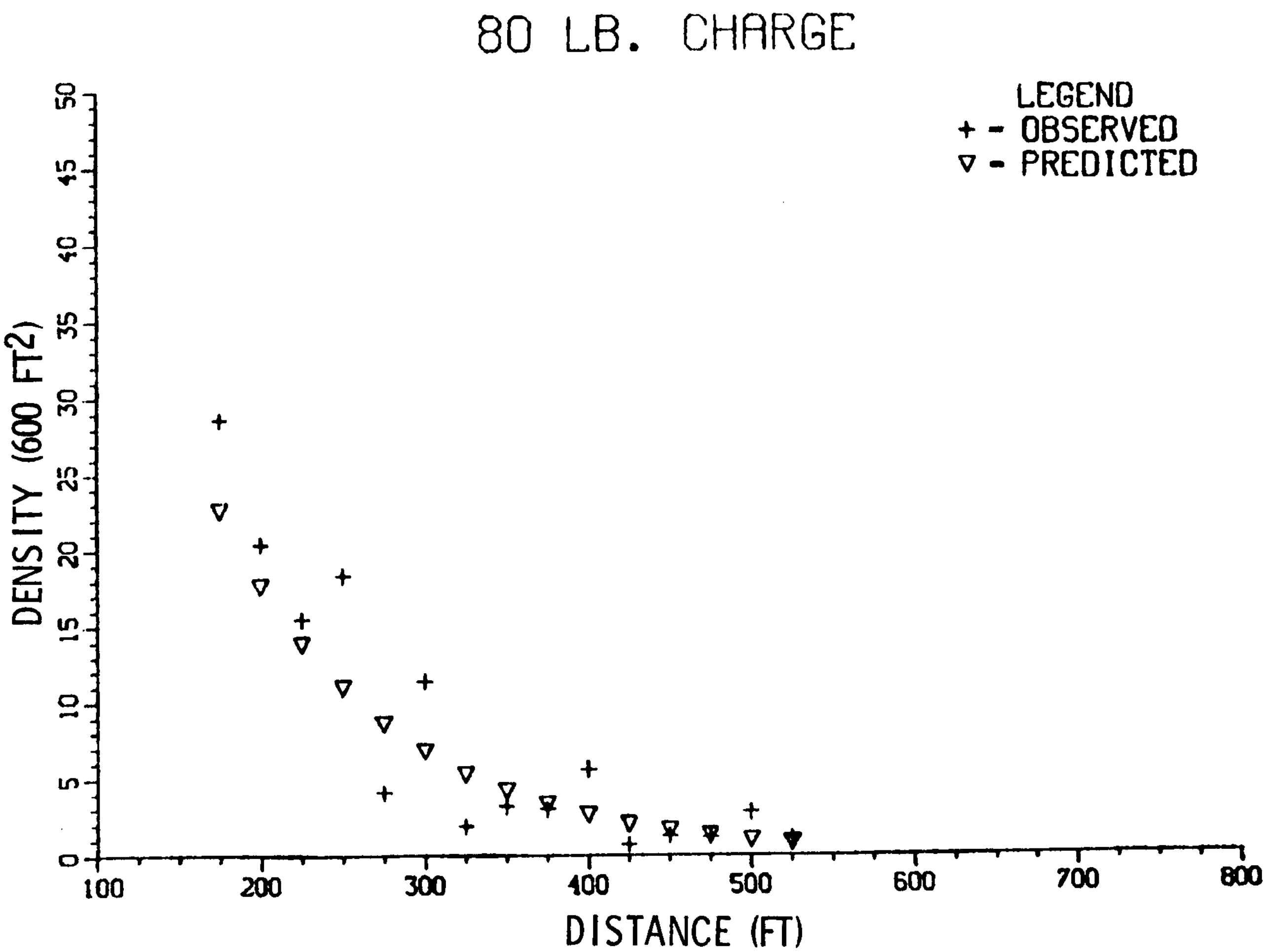


Figure 17. Hazardous Fragment (600 ft^2) Versus Distance in Front of an Igloo Magazine-36 Kg TNT Charge Positioned in the Center of the Igloo Statically Detonated.

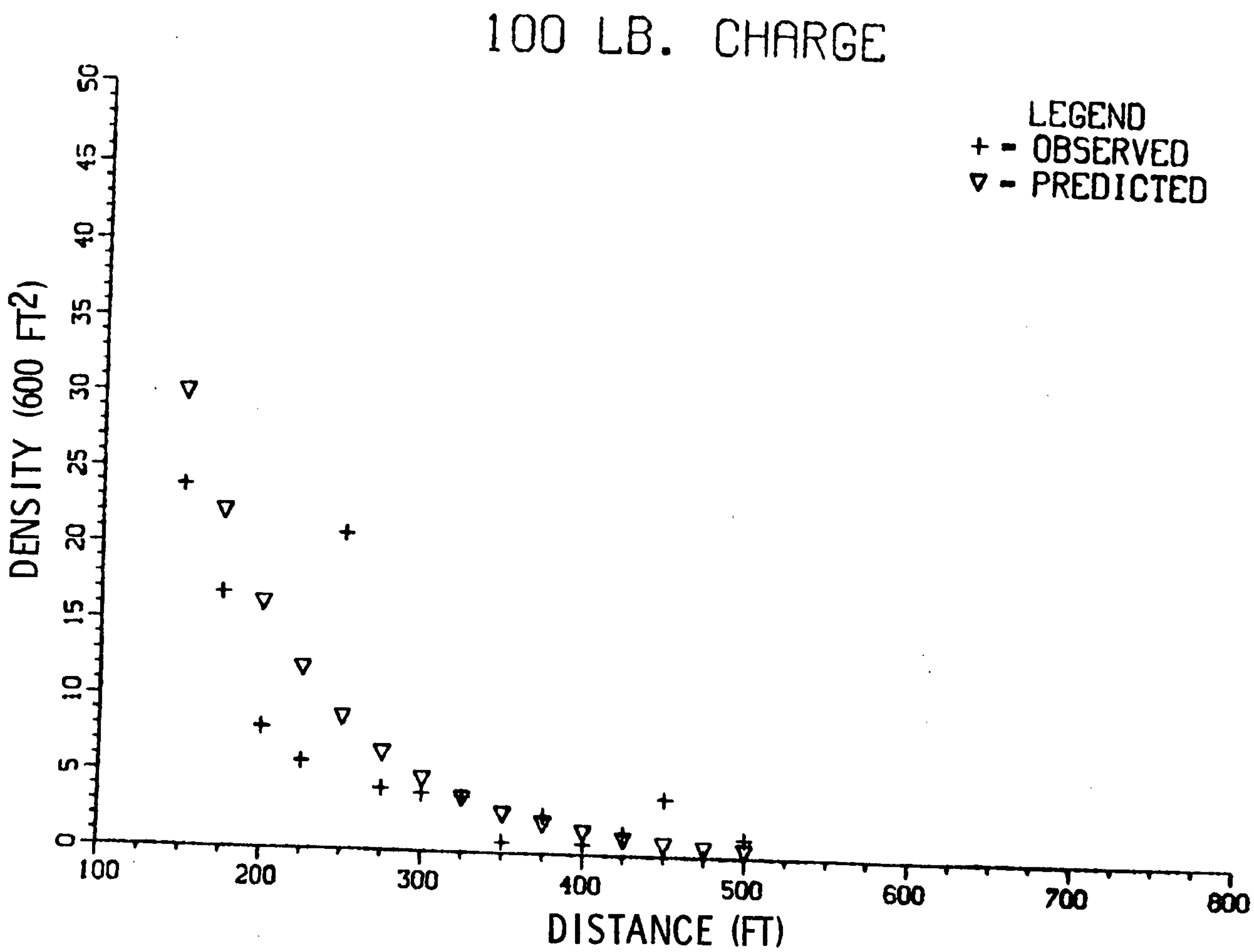


Figure 18. Hazardous Fragment Densities (600 ft^2) Versus Distance in Front of an Igloo Magazine-45 Kg TNT Charge Positioned in the Center of Igloo Statically Detonated.

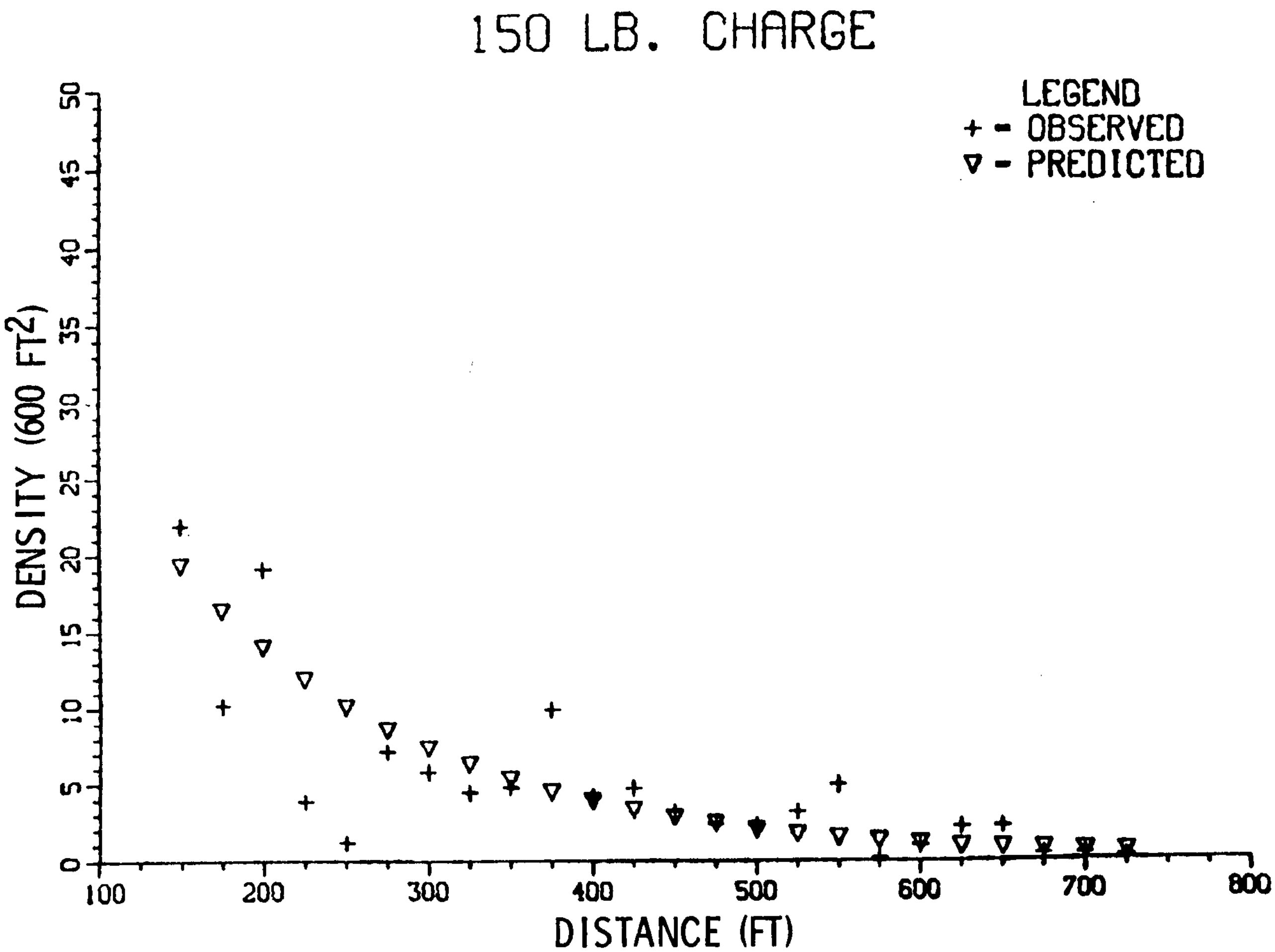


Figure 19. Hazardous Fragment Densities (600 ft^2) Versus Distance in Front of an Igloo Magazine-68 Kg TNT Charge Positioned in the Center of Igloo Statically Detonated.

The raw field recovery data are available* for each fragment in terms of its position and weight group. Only those fragments weighing at least 0.18 Kg (0.4 lb) were considered hazardous. While all of the fragments, weighing in excess of 0.18 Kg, for a given test were combined in arriving at hazardous density distributions, their segregation into weight groups has been preserved for future reference.

Attempts to measure initial headwall fragment velocities photographically were unsuccessful. The field of view between the headwalls and blast shields was obscured by combustion products and other debris before the headwalls failed and before the doors hit the blast shields. However, estimates of initial door velocities and the times-of-arrival of the reflected shock waves, between the headwalls and blast shields, were taken from the high-speed films and are provided in Table 4. The door velocity estimates are crude. The exact time that the doors hit the blast shield can only be estimated, and it is not known if the doors were accelerating when they impacted the blast shield.

TABLE 4. ESTIMATES OF INITIAL DOOR VELOCITIES AND TIMES-OF-ARRIVAL (TOA) OF THE REFLECTED SHOCK WAVES

Charge	Initial Door Velocity (mps)	TOA (msec)
5.4 Kg - 4 metres from the headwall	28	145
5.4 Kg - 20.4 metres from the headwall	41	81
7.3 Kg - 4 metres from the headwall	29	132
10.9 Kg - 4 metres from the headwall	50	131
45.4 Kg - 12 metres from the headwall	91	Not Observed

There is good agreement between the time-of-arrival measurements of the reflected shock wave obtained photographically and those obtained from the pressure transducers.

Harry Reeves and Walton T. Robinson, "Hastings Igloo Hazards Tests for Small Explosive Charges," US Army Ballistic Research Laboratory Memorandum Report ARBRL-MR-03356, May 1984.

DISCUSSION

The maximum explosive quantity which, when detonated inside the standard-size, earth-covered magazines used in this series of tests, produces no significant external effect was not determined due to door separation. These large wood-core doors were attached to the headwalls by three hinges that failed rapidly under all test conditions. The doors were observed impacting the blast shields and were recovered in areas off the side of the magazines. It is assumed that the doors could have traveled up to 150 metres in front of the magazines, at explosive charge weights of only 5.4 Kg, if the blast shields were not in place. The hazards associated with door separation, at low explosive charge weights, could be eliminated by employing fully vented doors; e.g., stretch chain link fencing fabric over metal door frames.

Variations in the structural response of the magazines, at HE charge weights up to 18 Kg, were not significant in terms of establishing hazardous fragment* distances; i.e., the maximum distance at which the hazardous fragment density is at least one per 600 ft^2. The sidewalls and arch crest of the magazine either remained standing or fell to the floor at these low charge weights. The sidewalls were blown out and recovered in large pieces off the sides of the magazines. The headwalls tended to break up into smaller pieces as the charge weight increased with more and more of them being projected over the blast shield and to the sides of the magazines. An apparent reversal in this trend can be found in Table 3, where the hazardous fragment densities for the 36 Kg test were greater than those for the 45 Kg test. However, an examination of the individual fragment recovery data for these two tests show that more fragments were recovered outside the 45-degree recovery zone in the 45 Kg test than in the 36 Kg test.

The maximum distance at which the hazardous fragment density exceeded one per 600 ft^2, in these tests, was greater than that observed in the Navajo tests at identical explosive charge weights (68 Kg). These differences are assumed to be real and the result of a different door and headwall design. The presence of the blast shield did not affect maximum hazardous fragment distances. Those fragments that traveled the farthest came from the top of the headwall and were projected over the top of the blast shield. However, the blast shield did stop many fragments; and had it not been in place the density close in would have been much greater. Fragment hazards to the front of the magazines could have been eliminated in this series of tests if the blast shields had been higher. Unfortunately, employing higher blast shields to control fragment hazards in front of the magazines, at small HE charge weights, would increase hazardous fragment densities to the sides of the magazines.

**Any fragment weighing at least 0.18 KG (0.4 lb) is assumed to be hazardous.*

If the headwalls and doors were replaced with chain link fencing fabric, full venting would occur; and fragments would not be produced by these currently used structures. In this case, thousands of pounds of explosives would be required to produce overpressures to the front or fragment hazards to the sides and rear of the magazine, which are unacceptable. Primary fragments from any ordnance items stored in the magazines could be controlled via sandbag barrier walls.

The non-hazardous overpressures measured off the side of the headwall in this series of tests, with an HE charge weight of 68 Kg, were slightly higher than those observed in the Navajo tests (8.5 kPA at 27.4 metres versus 3.4 kPA at 24.4 metres) at the same charge weight. The increase can be attributed to the presence of the blast shield in the Hastings test, the relatively heavy steel doors on the Navajo magazines, and variations in the design of the headwalls.

CONCLUSIONS AND RECOMMENDATIONS

The maximum distance requirement between inhabited buildings and standard-size, earth-covered igloo magazines containing small explosive charge weights will be determined by door displacement and not by concrete fragments from the headwall. Blast shields will reduce this distance and change the direction of the hazard from the front to the sides at small charge weights.

Blast shields are effective in controlling concrete fragment hazards from the headwalls at explosive charge weights up to 18 Kg. At higher explosive charge weights, significant numbers of fragments will be projected over the blast shield.

Igloo magazines will suffer severe structural damage when explosive charges as small as 5.4 Kg TNT detonate inside a magazine. Explosive charge weights of 7.3 Kg can completely destroy a magazine.

There are no significant overpressure hazards outside of a magazine associated with the detonation of up to 68 Kg TNT inside a magazine.

Tests should be conducted to determine overpressure and fragment hazards when explosive charges are detonated inside igloo magazines with fully vented non-fragment producing headwalls and doors.

Velocity of Debris from Bursting Explosives Storage Bunkers With Soil Overburden

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Abstract:

The velocity and range of roof fragments of an earth covered vented bunker on detonation of a mass of explosive contained therein has been calculated by means of a simple analytical technique, devised originally for calculating the velocity of fragments from bursting pressurized-gas vessels [1].
A 1/10 scale model experiment gave a result very close to the predicted values. Also, a recent incident with a 200-kg HE charge in a 250-m^3 bunker gave evidence that agreed well with the results calculated by both the debris range and the appurtenance range (venting-area-hazard) approaches presented here.

1. The Problem

An abandoned open coal bunker close to several other buildings had been looked upon as possibly being usable for storing, and for machining, a certain quantity of high explosive material.

The idea was to give the bunker a 30 cm thick concrete roof and to cover up the whole structure by 3 m of earth. The side walls were underground, so no problem was expected from these. However, there was a certain uneasy feeling about how far fragments and debris of the concrete roof would be thrown in the case of an event.

Calculation (see Section 2 and 3 below) gave a result that was felt could not be trusted, so it was decided to make a check by means of a model experiment.

2. The Calculation Procedure

It was the aim to calculate the velocity of the bunker roof as a whole, or fragments thereof, as if it were a homogeneous layer instead of one made up of concrete and earth (due to shock reflection, the loose earth overburden was expected to acquire a higher speed than the concrete, but this was considered less critical with respect to danger).

Owing to the fact that the bunker had a considerable venting area (~15 m²), calculation from the detonating high explosive's (multiple) shock impulse was considered not adequate. So, to arrive quickly at a result of the right order of magnitude, the following approximate procedure was adopted.

2.1 *"Determine the quasi-static pressure, p, in the closed bunker immediately after detonation of the high explosive, neglecting all venting areas and neglecting energy dissipation".*

By mixing the mass m_{ex} of detonated high explosive (having detonation temperature T_{CJ}) with the mass m_a of air (at temperature T_0) that is contained in the bunker, and

assuming that both the reaction products and the air have identical and constant heat capacities, temperature T in the bunker right after detonation is (see also Appendix A):

$$T = \frac{m_a \cdot T_o + m_{ex} T_{CJ}}{m_a + m_{ex}} \qquad (1)$$

The **density** of the mixture of gases in the closed bunker is

$$\rho = \frac{m_a + m_{ex}}{V} \qquad (2)$$

where V is the internal volume of the bunker.

With an explosive whose reaction products, per unit mass and at normal ambient conditions (p_o, T_o), occupy the volume v_{ex}, the mixture of air plus reaction products in the closed bunker would have pressure

$$p_1 = \frac{p_o \, (V + v_{ex} m_{ex})}{V} \qquad (3)$$

after cooling to normal temperature, T_o.

Right after detonation, the quasi-static pressure in the bunker would therefore roughly be

$$p = \frac{p_o \, (V + v_{ex} m_{ex})}{V} \cdot \frac{T}{T_o} \qquad (4)$$

with T from Eq. (1).

Values of T_{CJ} and v_{ex} can be found in the literature.

2.2 *"Determine the speed of sound, a, in the gas mixture inside the bunker".*

Assuming that right after detonation the gas mixture (air plus reaction products) will behave as a perfect gas with given adiabatic exponent γ, the speed of sound in the bunker is:

$$a = \sqrt{\frac{\gamma p}{\rho}} \qquad (5)$$

2.3 *"Determine the Characteristic Discharge Time,* t_o [1], *of the gas from the bunker".*

The area through which gas can escape from the bunker is made up of the venting area F_v plus the area F of any arbitrary bunker roof fragment that is being pushed out by the gas pressure. The portion m_F of gas that will escape through the hole of area F left by the considered roof fragment, is

$$m_F = m_G \left(\frac{F}{F + F_v} \right) \tag{6}$$

where m_G is the total mass of gas contained in the bunker right after detonation (i.e., roughly $m_G = m_a + m_{ex}$).

Only this portion m_F will contribute to accelerating the roof fragment. The "characteristic discharge time", t_o, defined in [1] (see also [2]) is thus

$$t_o = \frac{4\, m_G}{\rho_c v_c F} \cdot \left(\frac{F}{F + F_v} \right) \tag{7}$$

where ρ_c and v_c are the choked-flow density and velocity derived from the density, ρ, and speed of sound, a, as given by Eqs. (2) and (5), respectively.

2.4 *"Determine the fragment velocity,* v_p*, by the procedure proposed in* [1]*".*

It is convenient to assume a reasonably small "jet-propelled" fragment presenting an area F to the gas pressure, and to calculate its velocity v_p by the simple procedure suggested in Sections 2 and 4 of [1], with $v_o = 0$ (see also Section 2.2 in [2]). Formula for v_p see Appendix C below.

The most conservative result (highest achievable "limit" velocity) would be obtained by calculating for a very small fragment.

This procedure was originally devised for calculating the velocity of fragments from bursting pressure vessels,

but the analogy to a bursting bunker is obvious, and calculation with the "venting factor" of Eq. (6) and with the approximate gas properties calculated as suggested above gave a result which agreed well with a model experiment.

2.5 *"Determine the maximum range, x, of the fragments".*

A conservative result is obtained by assuming that bunker fragments are thrown out at an angle of 45 degrees and will experience no drag. The maximum possible range is thus

$$x = v_p^{\,2}/g \tag{8}$$

where g is the gravitational acceleration ($g = 9.81\ m/s^2$).

3. Result of Calculation

The real bunker is 10.5 m long, 3.5 m wide, and 4.5 m high. The roof would weigh about 5400 kg per square meter (0.3 m concrete, 3 m soil). The open front end constitutes a venting area of ~15 m².

The mass of high explosive that might go off was assumed to be 500 kg, its detonation temperature was assumed at 4000 K **[3]**, and the gas volume of the reaction products at normal ambient conditions was taken equal to 0.8 m^3/kg **[4]**. All forces restraining the roof or fragments thereof, such as reinforcement or even the bonding within the concrete itself, were neglected. Any fragment would therefore be accelerated by the gas only against its own inertia.

With an average assumed $\gamma = 1.4$, the initial velocity of a small fragment, as calculated by the above procedure, should be about 6.1 m/s in the limit; a roof section of 1 m² area would reach about 5.8 m/s. Assuming ideal ballistic conditions, i.e. projection at an angle of 45° and no drag, this would mean that a 1 m² roof slab would fly 3.4 m at most, and that no portion of roof debris can be thrown farther than 3.8 m by a detonation of 500 kg of the high explosive considered.

4. The Model Experiment

The scaling laws derived from the set of gas dynamic equations [5, 6, 7] state that on reducing a flow field in its linear dimensions by a factor S, volumes, masses and energies (such as, e.g. a detonating quantity of high explosive) would scale down as S^3, whereas pressures and velocities remain the same in the original and in the scaled down model. Naturally, this holds true not only for flow and phase velocities, but also for the velocities of properly scaled down (or up) bodies accelerated by the flow.

The model experiment was chosen so that the original bunker configuration was scaled down by a factor $S = 0.1$.

The 1/10-scale bunker was built with a 25 mm thick aluminum roof, instead of a model-size (30 mm thick) concrete roof, and was covered about 30 cm high with sandy soil (see Fig. 1; soil overburden retained at bunker entrance by the visible plywood plate which is kept by two wooden poles).

A cylindrical TNT/RDX high explosive charge weighing 0.5 kg - corresponding to 500 kg - was placed 0.7 m deep inside the bunker, 0.05 m above the ground (corresponding to 7 m and 0.5 m in reality).

The charge was detonated, and the event was observed from a safe distance, and was also recorded with a high-speed camera at 450 frames per secound.

The result (see Fig. 2) showed that the soil overburden had been scattered around in a circle not greater than about 3.5 m in radius.

Unfortunately, because of the detonation fumes, the true height to which the soil and the aluminum roof had been thrown was not clearly visible. Anyway, the aluminum roof plate's culminating point was around or below 2 m, and the plate came down to nearly where it had started from.

According to the scaling laws of gas dynamics, the same should happen to the full-size bunker, i.e. debris (fragments) should acquire the same velocity as in the model experiment, thus being thrown no farther than about 3.5 meters.

5. Conclusion

The close agreement between the calculated and experimental results appears to show that this approximate procedure is suitable to predict fragment hazards from explosives storage bunkers, shelters and similar structures, and to establish the necessary safe distances in an easy manner.

It should be mentioned, however, that the accompanying blast hazards should not be forgotten. (cf. also Appendix B.)

6. References

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APPENDIX A : *Gas Temperature*

Acceleration of fragments is very sensitive to the velocity and, hence, to the temperature of the escaping gas.

Literature data on the detonation temperature (Chapman-Jouguet temperature, T_{CJ}) of an explosive differ within a wide range, depending on the detonation conditions and on the equation of state used.

Furthermore, the use of a detonation temperature in the sense of a state variable is only limited since a detonation is a nonequilibrium process.

The temperature *after* detonation, however, is governed mainly by the energy released *during* detonation. Therefore, a guess on the temperature T of the mixture of air plus reaction products can be obtained by using the high explosive's heat of explosion q_{ex} (which is usually known and is given in Joules/kg) and an approximate value of the specific heat capacity, c, of the hot air plus reaction products mixture on the basis of the molecular weights of the component gases; a reasonable guess for military high explosives is an average of $c \approx 1200$ Joules/kg·K.

The temperature T needed in Eq. (4) can then be found from the simplified energy equation:

$$m_G cT = m_a c_a T_o + m_{ex} q_{ex} \tag{1a}$$

For the bunker of above, and with $q_{ex} \approx 5.5 \cdot 10^6$ J/kg [4], and $c_a \approx 1000$ J/kg·K for the air, we obtain $T \approx 3300$ K, whereas with $T_{CJ} = 4000$ K as assumed in Section 3 we found $T \approx 2900$ K from Eq. (1).

APPENDIX B: *The Venting Area Hazard*

The portion of gas escaping through the venting area F_V is

$$m_V = m_G \left(\frac{F_V}{F+F_V}\right) \tag{6'}$$

according to Eq. (6), where F is the area of the accelerated roof (or wall) fragments.

From a safety point of view one may argue that there might be no fragments at all, so

$$m_V = m_G \tag{6''}$$

which means that the entire mass of gas in the bunker after detonation of the high explosive is available to accelerate machinery, doors, furniture etc. through the venting orifice. It is obvious that this, and the gas blast itself, present a major hazard, mainly downstream of the bunker.

From Eq. (7), the characteristic discharge time t_{ov} relating to the venting area F_V is therefore

$$t_{ov} = \frac{4\ m_G}{\rho_c v_c F_V} \tag{7'}$$

Hence, the maximum velocity v_p of an appurtenance accelerated by the gas through the venting orifice follows from Eq. (a) of Appendix C, with t_o replaced by t_{ov}, and from Eq. (b) with F being the area which this appurtenance presents to the gas flow.

APPENDIX C : *Fragment Velocity*

To calculate the fragment velocity v_p, first calculate the acceleration time t by solving the equation

$$t^2 \alpha a \sqrt{\frac{2}{\gamma+1}} \cdot e^{-t/t_o} + 2t - t_o = 0 \tag{a}$$

Then,

$$v_p = \frac{2\alpha t a^2 e^{-2t/t_0}}{1+\gamma+\alpha t a \sqrt{2\gamma+2}\, e^{-t/t_0}} \qquad \text{(b)}$$

Here, $\alpha = \rho F/m_p$, where m_p is the mass of the fragment. The remaining quantities are defined in Section 2 above. For details of the calculation see [1] or [2].

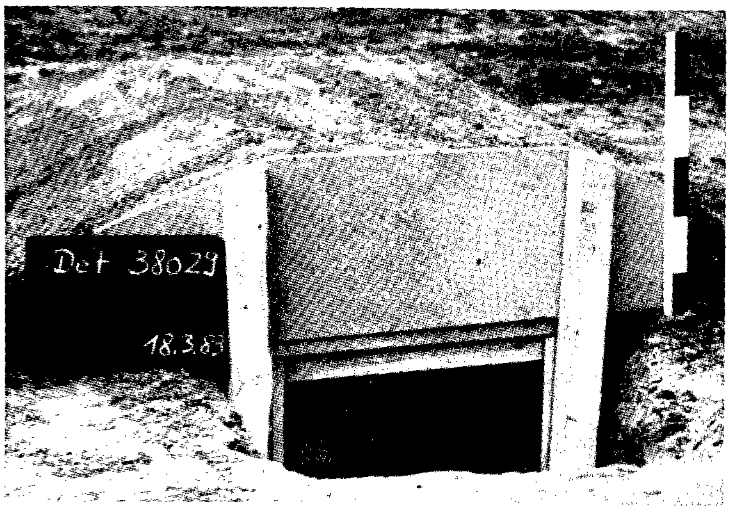

Fig. 1: Scale model bunker before trial.

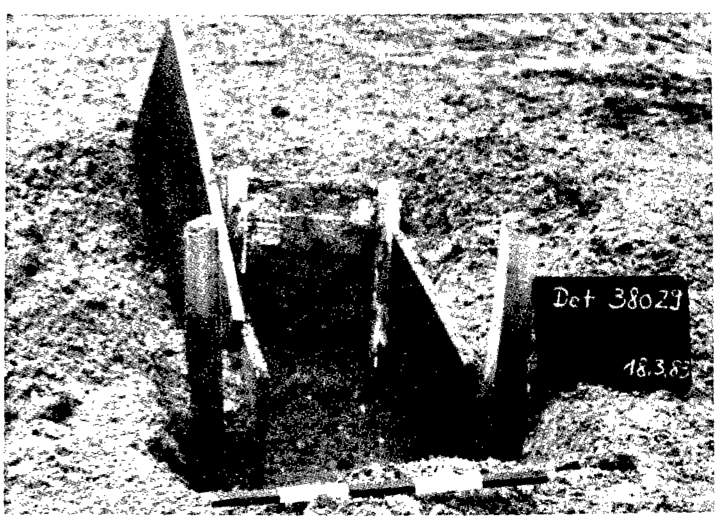

Fig. 2: After trial.

UNITED STATES DEPARTMENT OF DEFENSE

EXPLOSIVES SAFETY SEMINAR

27 - 30 AUGUST 1984

DESTRUCTION OF PROPELLANT MAGAZINE
NOVEMBER 1982

AUSTRALIAN EXPERIENCE WITH LONG TERM STABILITY OF DNT COATED SINGLE BASE PROPELLANTS

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DESTRUCTION OF PROPELLANT MAGAZINE - NOVEMBER 1982

AUSTRALIAN EXPERIENCE WITH LONG TERM STABILITY OF DNT COATED SINGLE BASE PROPELLANTS

Although single base propellants have been around for one hundred years, production of this type of propellant in Australia only commenced during World War 2 when appropriate plant and know how were provided under the Lend Lease Scheme. Prior to this date all propellants for SAA through to large calibre ammunition had been of the British double base type.

Most of the single base propellants made at Mulwala Explosives Factory have been of the IMR type i.e, single perforated tubular granules with their surface coated with DNT for use in small to medium calibre ammunition.

Since production started at Mulwala Explosives Factory in 1944 some fourteen different versions of style of propellant have been manufactured. Four versions only were made up until 1957 and these were identified with an IMR type number matching the US propellants from which they were copied. New varieties introduced since 1957 have been identified with an AR series number commencing with AR2201 - the original Australian 7.62 mm rifle propellant.

Until recently it was believed in Australia that these sorts of propellants had a safe storage life well in excess of thirty years at ambient temperature. In November 1982 this belief was shattered by the sudden cataclysmic destruction of a transit storage magazine at Mulwala Explosives Factory. The investigating committee concluded that the cause of this incident was the spontaneous ignition of a small quantity (approximately 50 kg) of IMR4740, about twenty five years old, stored in the magazine.

It is interesting to note that this event was a typical UN HD 1.3 one. This vindicated the classification assigned to this propellant following the trials described in the paper I presented earlier in this conference.

FIGURE 1, shows that of all types of propellant produced at Mulwala, AR2201 is the most common having been produced more or less continuously for twenty years from 1958. Our reference collection of this propellant was extensive and it was decided to concentrate our efforts and investigations on this type. All further comments relate to that propellant unless otherwise indicated.

Our investigation was directed towards obtaining data on what we had in storage and we quickly started a program of measuring stability by Abel Heat Tests and by determination of residual stabiliser content. The latter results were used to calculate a parameter, the average stabiliser consumption rate per annum and while it is recognised that this figure may have doubtful qualities, by using it we are attempting to eliminate the effects of different ageing times when comparing samples.

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FIGURE 2, shows a reasonable correlation for propellant over about five years old between the Abel Heat Test results and the stabiliser consumption rates, with the higher Heat Test results coming from the propellants with the lower consumption rates.

The checking turned up a large number of samples of DNT coated single base propellants which were severely deteriorated in terms of stability. Surprisingly the most deteriorated propellants were not the oldest but were relatively young - some as young as only ten years old.

Study of the results showed the samples fell into several distinct groups by time with similar stability results occurring within each group. Essentially the groups were:

(a) Material made 1944-1950 - moderate stability
(b) Material made 1950-1958 - very poor stability
(c) Material made 1958-1965 - excellent stability
(d) Material made 1965-1973 - poor to bad stability
(e) Material made after 1973 - variable stability ranging from very good for young material to poor for older material.

These are shown diagrammatically in FIGURE 3.

The next step was to try to explain this and we thoroughly examined the stability tests which had been done at the time of manufacture. The Methyl Violet Paper stability test at 134°C is used as a routine acceptance test in Australia.

However we could find absolutely no correlation between MVP results and the observed long term stability. As all initial tests were over the forty minutes required by specification, we had taken this to show adequate long term stability but have now concluded that this is NOT so and that the MVP test only indicates a life of at least five years.

The implication is that if storage for longer than five years is contemplated, regular surveillance is essential.

The second investigatory approach was to look at the records for the manufacturing methods employed over the years to see if slight variations had been adopted for any particular reason in either the processes or the formulations.

We were successful in this regard.

Group (c) gave us the clue. Our user, the Australian Army, noted that equivalent British propellants contained chalk and required to do the same for propellant AR2201. The UK added powdered chalk to the NC prior to mixing. This was felt to be as a stabiliser for the NC if it was to be stored for any length of time between manufacture and mixing. However as our practice was to mix within a week of manufacture of the NC blend we added the chalk at the mixing stage.

However in 1965, in order to reduce the smoke produced on firing and because it was felt that the diphenylamine was an adequate stabiliser it was dropped from the formulation. All the following production has had poor to bad stability once the initial five to ten year period is passed.

But why did the pre 1950 production still have better stabilities than the 1950-1958 production? It was subsequently discovered that at this time small quantities of diphenylamine stabiliser had been added with the DNT at the coating stage and that this was discontinued at this time.

But again there was a very small group of lots produced in 1966 which had significantly better Abel Heat Test results and lower stabiliser consumption rates even though they did not contain calcium carbonate. These were given much reduced water drying steeping as part of an experiment to assess the effect of water soaking times on ballistic performance.

In summary, the effect is shown in FIGURE 3 and it is believed that the following factors were important in achieving satisfactory long term stability:

(i) inclusion of a small amount of diphenylamine stabilizer with the DNT coating material during the coating process (used between 1944 and 1950);

(ii) incorporation of a small proportion of calcium carbonate into the propellant during mixing (used between 1958 and 1965);

(iii) major reduction of water drying and steeping time (used for several samples without calcium carbonate present in 1965).

It is hypothesized that these factors are all inter-related. Testing of the water from the water dry process shows that "small" amounts of diphenylamine stabiliser can be leached out of single base propellants while they are being soaked in water. Previously it was believed that the loss of stabiliser was uniform throughout the grain and therefore inconsequential. However if the loss is assumed to be concentrated near the surface then obviously prolonged soaking can lead to a surface layer with no stabiliser present at all. If the grain is then coated with a relatively impermeable material, e.g., DNT, acidic decomposition products from the surface layer may build up inside the grain leading to accelerated decomposition and a short storage life. Should the grain matrix contain some other water insoluble alkaline material such as calcium carbonate or if the diphenylamine leached out in water dry is replaced during the coating, then the above accelerated decomposition mechanism will not operate and satisfactory long term stability can be achieved. Figure 4 illustrates the proposed mechanism for the case of added calcium carbonate.

While more work needs to be done to confirm the above hypothesis Australia has nevertheless reverted to the incorporation of a small amount of calcium carbonate into the propellant matrix for all future production of DNT coated single base propellants. The total amount of inorganic material is controlled so that smoke is not excessive. This approach is seen as providing a readily verifiable method of achieving a satisfactory long term stability with such propellants. It is considered the approach would also be applicable to other coated single base propellants which undergo some form of solvent or water leaching during manufacture.

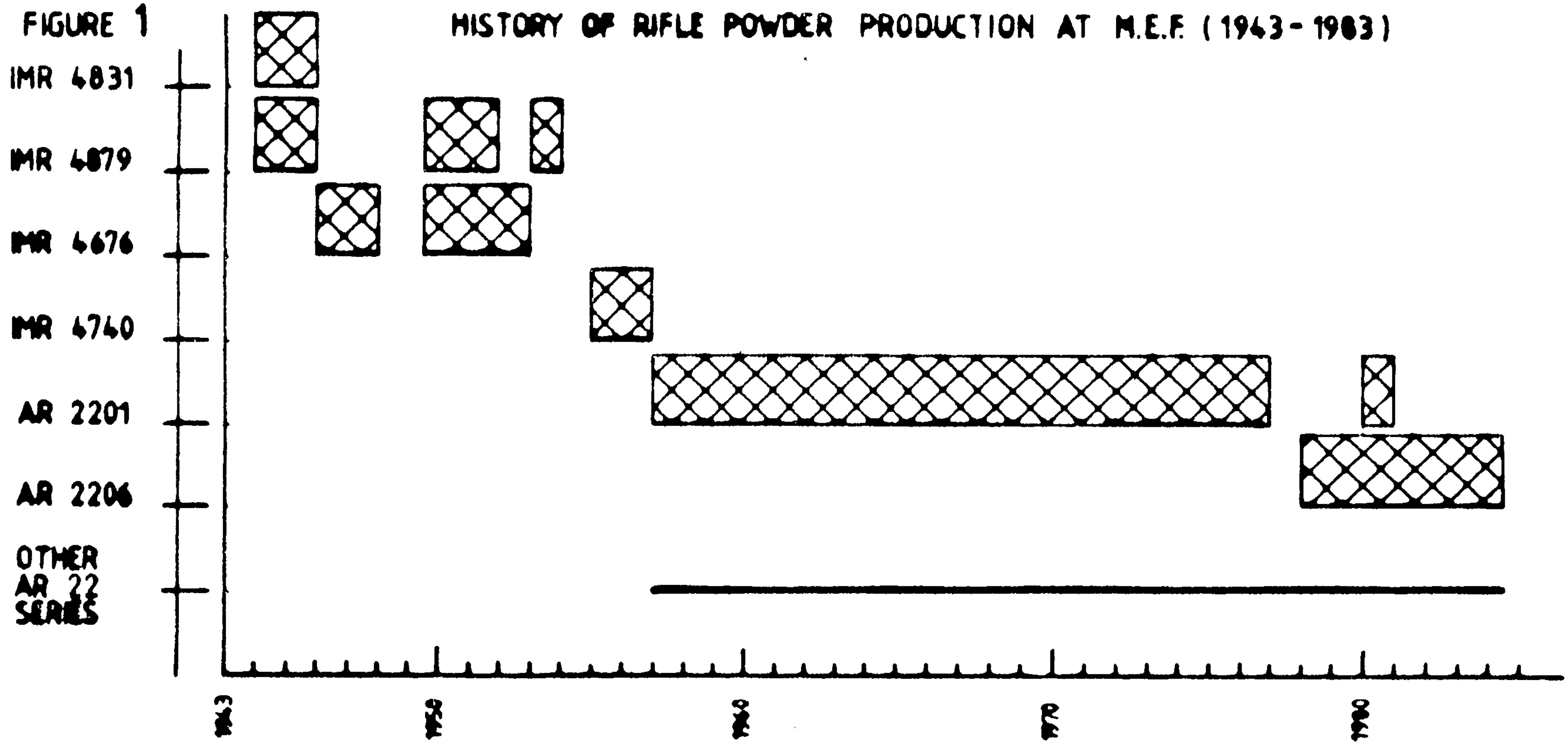


FIGURE 1 HISTORY OF RIFLE POWDER PRODUCTION AT M.E.F. (1943 - 1983)

FIGURE 2

AR 2201 REFERENCE SAMPLES

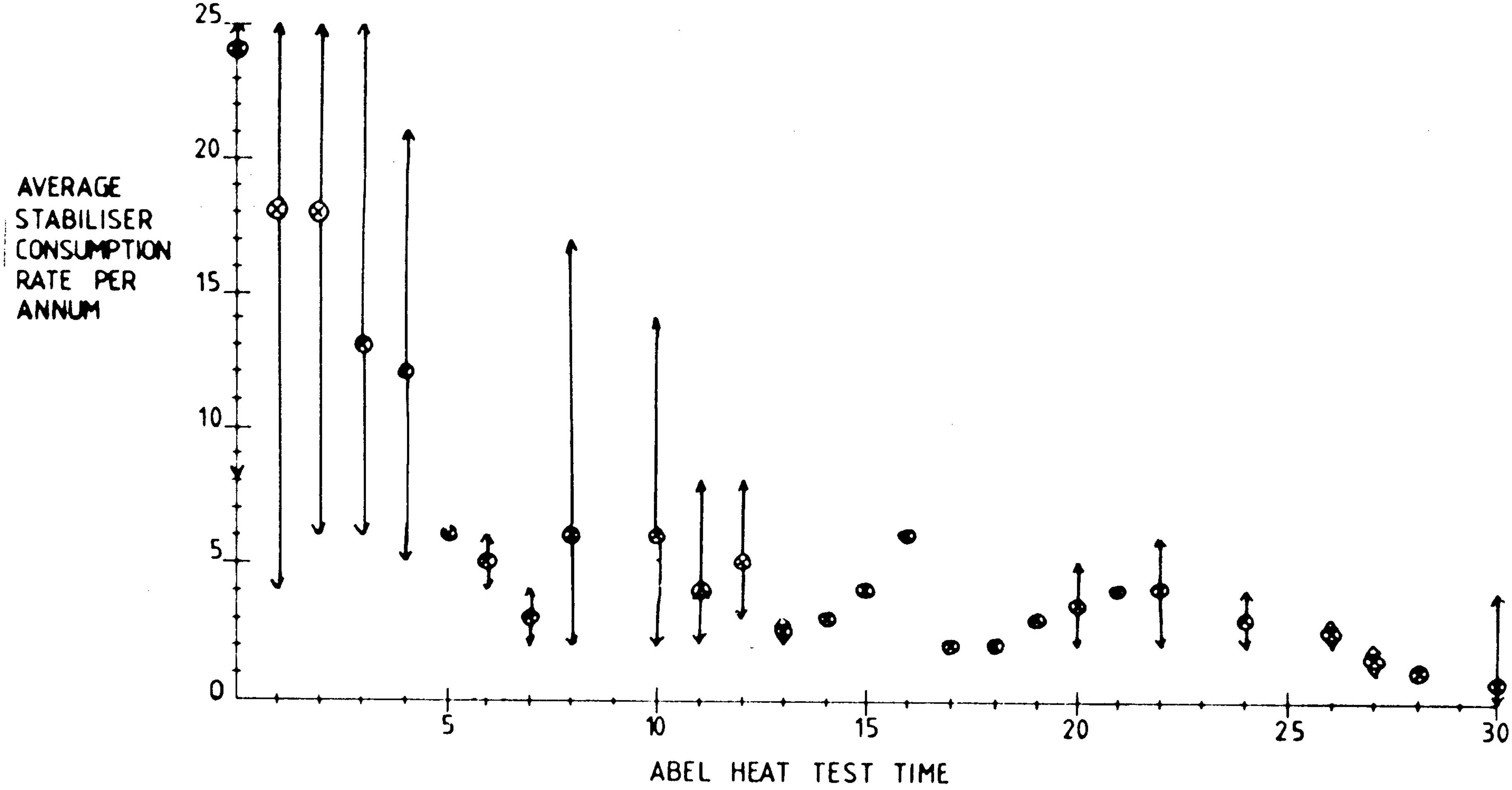


FIGURE 3

AR 2201 REFERENCE SAMPLES ABEL HEAT TEST AT 82·2° C

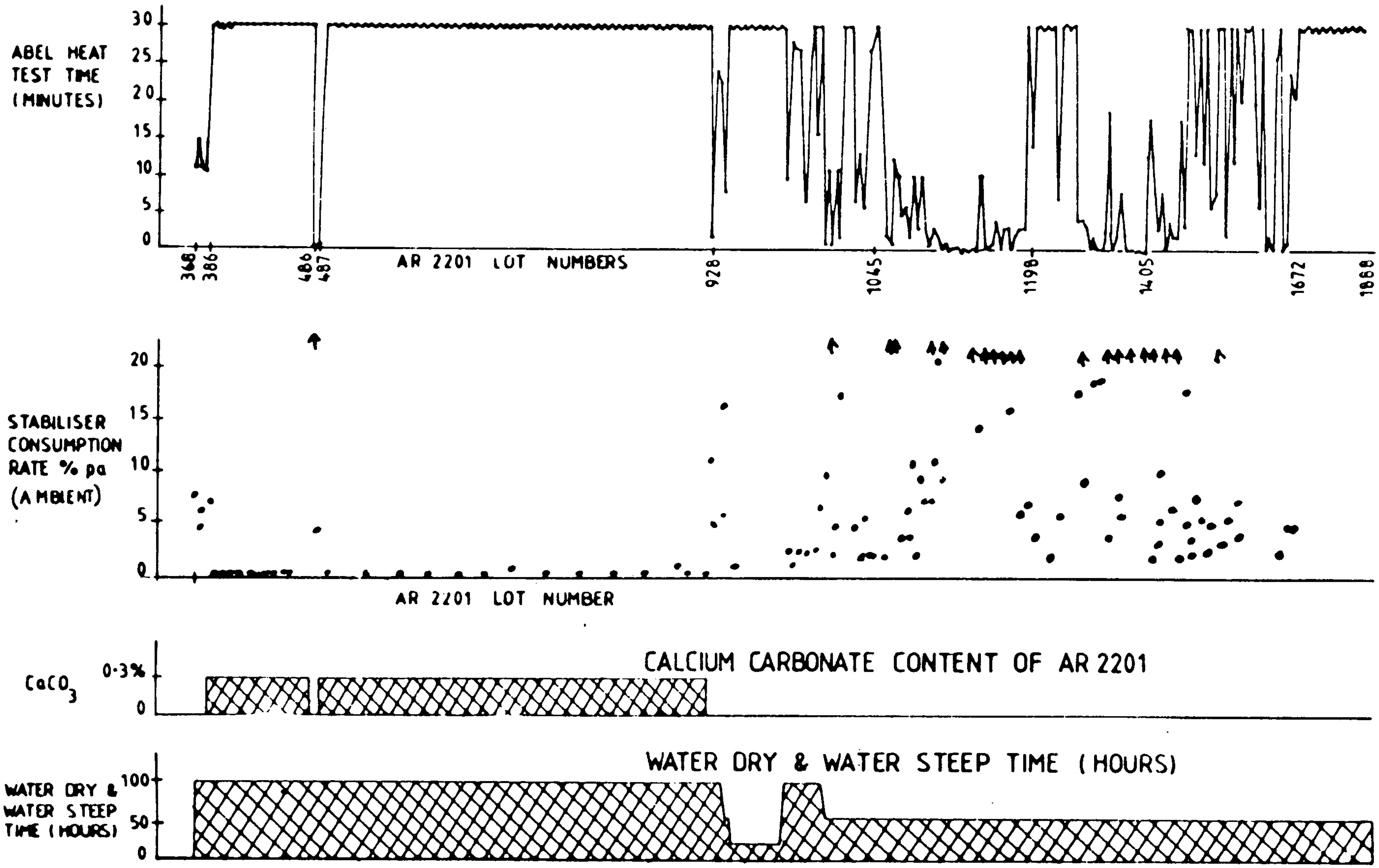
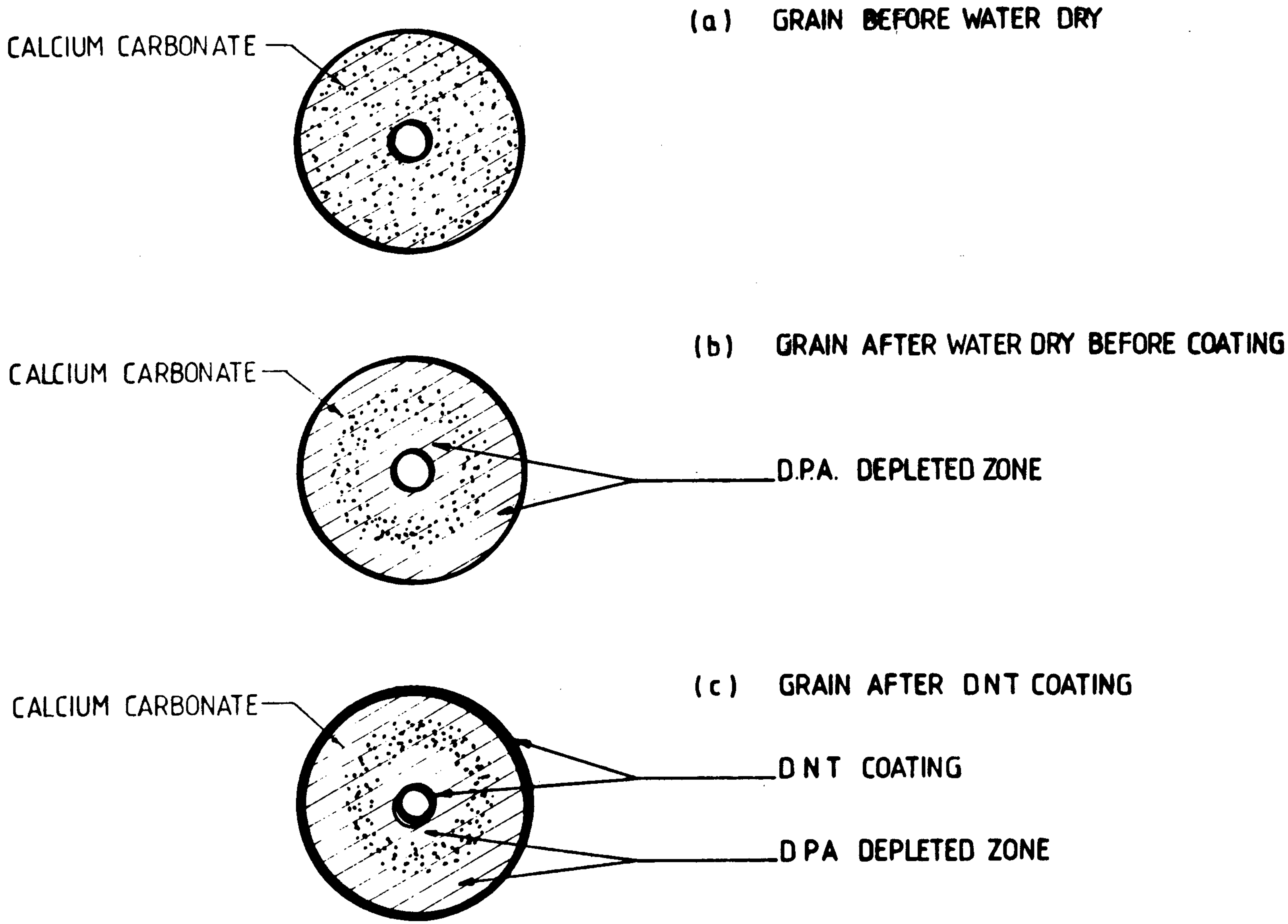


FIGURE 4


CALCIUM CARBONATE
(a) GRAIN BEFORE WATER DRY
CALCIUM CARBONATE
(b) GRAIN AFTER WATER DRY BEFORE COATING
D.P.A. DEPLETED ZONE
CALCIUM CARBONATE
(c) GRAIN AFTER DNT COATING
DNT COATING
DPA DEPLETED ZONE

EVALUATION OF MATERIALS FOR THERMAL PROTECTION

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ABSTRACT

An on-going program to provide improved thermal protection for pyrotechnic operators is described. The critical first step in providing improved personal protection is to insure that the best available material is used to provide the outer shield. Researchers and manufacturers are continually introducing new materials, but they have not been tested against the special kind of thermal threat presented by pyrotechnics. A method of comparative testing of fabrics and other materials is described, and the results obtained with some of the latest available varieties of fabrics are discussed.

BACKGROUND

The manufacturers of protective clothing, the producers of fabrics, and the researchers who develop new fibers and blends are not aware of the particular characteristics of the thermal threat posed by protechnics. Even those in the pyrotechnics industry have had little basis for making a rational decision in selecting one type of protective clothing over another. Past experiences and traditional selections give no guidance when new materials are continually being introduced.

The problem of developing improved protection for workers against pyrotechnic burns poses the major question of finding what sort of fabric or material offers the best protection against heat of the sort that pyrotechnics may produce. Since pyrotechnic materials themselves vary greatly in their thermal output characteristics, the decision was made to test the fabrics against a heat source which would replicate some of the most severe thermal threat characteristics posed by the "hotter" pyrotechnic mixes.

TEST PROCEDURE

Laboratory tests were designed to give a preliminary answer to the question of which material would best withstand a severe heat threat. Tests performed in a laboratory situation permit carefully controlled comparisons to be made. The characteristics of the heat source can be identified and regulated, the distance that the samples will be positioned can be replicated, and the time of exposure can be carefully controlled. In the experiments reported in this paper, the heat source was an oxyacetylene torch; the samples were placed 4 inches from the orifice of the torch; and time exposures of various durations were permitted by means of a mechanical shutter. The sample of material to be tested was placed in a ring holder in front of the flame, the torch was ignited, and the shutter was put in motion to expose the sample to the sudden onset and offset of a very intense heat source in excess of 2600°F. (The apparatus is depicted in Figure 1.) Time/temperature changes were recorded with a fast response thermocouple (Hy-Cal Engineering Zig-Zag No. TC-2345-A).

Field tests conducted with various mixes and quantities of pyrotechnic blends confirmed the findings of the laboratory tests with the oxyacetylene flame. Field tests using pyrotechnics were more difficult to conduct, produced more variations in the heat output and in the time course of the release of heat, and required a greater number of replications of tests in order to be sure that the data obtained for a particular fabric were reliable and valid. As a result of the extensive series of tests with pyrotechnics in the field, it was decided that equally valid and more reliable data could be obtained with the experimental apparatus using the oxyacetylene flame in the laboratory.

Because it is not possible to accurately record the time/temperature variations in either a high yield pyrotechnic burn or in an oxyacetylene flame, the exact nature of the thermal threat cannot be determined. There apparently are no sensors or detectors that can respond rapidly and accurately to such sudden bursts of heat; but the technology does exist to record the heat rise on the protected side of the material being tested. It is possible, therefore, to record the time/temperature variations for several types of fabrics and to compare them with data received from identical fabric samples

used in another test condition. When the results of the two series match, the thermal threat may be considered to be the same for both sets of tests.

By comparing the resultant time/temperature curves for one type of material against those obtained with another type of material, it is possible to make a comparative evaluation. Because the protective characteristics of different materials vary with different extents of exposure, a sequence of tests should be run with different exposure times. Figure 2 depicts the maximum temperature rises obtained on the protected side of samples of materials for a 0.5 and a 1.0 second exposure to the oxyacetylene flame. The materials were arranged in order of decreasing thermal protection (increased transmittal of heat) for the 0.5 second exposure. When the same materials were tested at the 1.0 second exposure, several of the materials no longer proved to be as comparatively effective as they had at the shorter time. Leather was still the best, but the others had shifted in their comparative effectiveness.

The temperature rise curves for leather have consistently been found to be slow and gradual, whereas those for most of the synthetic fabrics have sharply steeper rises. Of the synthetics, the aluminized kynol generally has had one of the slower and lower rises across a wide variety of exposure times. Figure 3 depicts the differences between the temperature increases experienced with the leather and the aluminized kynol for the 0.5 second exposure.

A finding made in some earlier research with protective suits made of aluminized rayon was that the used material, even in cases where the aluminized surface was badly abraded, gave better thermal protection than did the brand new material. The increased protection was determined to be the result of increased air gaps within the weave which slowed and reduced the temperature rise experienced on the protected side. A similar finding was made for aluminized kynol in this latest research series. Samples of aluminized kynol which had been worn at intermittent times for over 18 months were consistently found to have lower time/temperature curves than were found with brand new material.

Tests conducted with samples of kevlar, rayon, and other synthetic fabrics which had been tested in earlier series showed results that were

consistent with what was already known about their response characteristics (see Figure 4).

Tests performed on a wide range of panox fabrics showed that all had higher maximum temperatures than the other, heavier, synthetics tested previously (See Figure 5). In addition, during the 0.5 second exposure, approximately half the samples of panox suffered from the heat and easily tore apart. This same finding has been found to occur with the majority of various blends of polybenzimidazole (PBI) tested.

The same series of materials was tested again using the longer exposure time of one second. Those materials which had performed poorly at the 0.5 second exposure and which had torn apart easily were not submitted to the longer burn. As Figure 6 shows, the samples tested for one second varied considerably from one another in appearance; some emerged from the burns relatively unscathed, whereas others shriveled badly or tore easily.

For the longer burns, leather again offered the best protection with the slowest and lowest time/temperature curve. Figure 7 depicts a typical curve for leather and for rayon. Figure 8 shows that the used or worn kynol again slightly outperformed the new kynol. Figure 9 shows typical curves for some kevlar and other synthetic fabrics, and Figure 10 shows the curves for the best-performing of the panox and PBI fabrics. It should be noted that out of the many varieties of panox and PBI fabrics tested, only one from each category remained relatively intact after the one second burn. Additional tests will need to be conducted to determine at what exposure times fabric failure will occur for these remaining samples.

One of the latest types of materials to be received for testing consisted of composites of nomex or SEF modacrylics with Goretex. Preliminary tests with these materials indicated that they were not especially good for thermal protection against high yield pyrotechnics. The samples shriveled badly and the recorded temperature rise was high. Such poor performance may generally be expected of synthetics of such light weight. What was surprising about these composites, however, was the strength of the Goretex membrane. If the membrane proves itself against longer duration exposures, it may offer the possibility of combining the Goretex with some other, lighter weight synthetics which would result in increased operator comfort

and ease of movement, while maintaining a high degree of thermal protection.

CONCLUSIONS

At the present time, leather has continued to prove itself the best material for providing thermal protection against pyrotechnics. Aluminized kynol and some of the heavier synthetic fabrics using kevlar are the best of the synthetics of those tested. Fabrics that had been subjected to wearing and washing demonstrated superior thermal protection over that provided by unused material. None of the newer synthetic fabric blends tested proved a worthy candidate to replace the ones earlier recommended, but the surprising strength of composites with the Goretex membrane suggested that improved combinations may result in the need for further reappraisal.

The need to continually test, evaluate, and reappraise the protective characteristics of different materials stems from the desire to provide the best thermal protection for pyrotechnic operators. As new products become available, there is always the possibility that one will prove to be better than the consistent leader, leather. But the need to evaluate new materials is also driven by changes in the marketplace. Aluminized kynol, the best of the synthetics, is no longer readily available. An on-going comparative evaluation of protective materials will always be needed.

Table 1. Fabrics Used in Thermal Tests.

Category Code	Description	Weight (oz/yd^2)	Temperature Rise (^oF) After Timed Exposure 0.5 sec Oxyacetylene	1.0 sec Oxyacetylene
LEATHER				
BL4	unal. Chrome Split	39.5	57	84
KYNOL				
YS	alum. Amatex	22.9	90	125.5
YSU	alum. Amatex (used 18 mos)	22.9	79	117
RAYON				
R6	alum. Gentex 1006	14.9	104.5	139
KEVLAR				
KH	unal. Amatex 11HT26	10.7	166	286
K4	unal. Amatex 22PT7	21.9	66	111.5
NOMEX				
NB	alum. Fyrepel black	9.8	----	242 TE
OTHER SYNTHETICS				
GT	unal. Amatex 24PT73WR	24.0	68	92.5
GN	unal. Amatex 16HT65WR	16.0	77	152.5
PBI/POLYBENZIMIDAZOLE*				
P96	plain 7PT96	7.2	358 Flame/TE	----
P94	plain 8PT94	8.3	390 Flame/TE	----
P101	twill 10TT101	9.5	302 TE	----
P64	herringbone 11HT64	10.8	212 TE	----
P85	herringbone 16HT85	16.2	153 TE	----
P36	plain 17PT46	17.4	173	224 TH
P38	plain 18PT38	18.1	225 Flame	----
P37	plain 22PT37	21.9	131	165
P35	plain 22PT35	22.4	170	182 TH

Table 1. Fabrics Used in Thermal Tests. (Contd')

Category	Description	Weight (oz/yd^2)	Temperature Rise (^{o}F) After Timed Exposure 0.5 sec Oxyacetylene	1.0 sec Oxyacetylene
GORETEX				
GB	Blue (SEF Modacrylic/Goretex/Nomex)	9.5	----	?
GO	Orange (Nomex/Goretex/Nomex)	8.5	----	224
PANOX				
P11	standard		236 TE	----
P21	undergarment		96 TE	----
P22	waterproof (UCF Coating)		100	134
P23/25	standard 90% Panox 10% Aramid		233 TE	----
P24	stainless steel + UCF Coating		96	183.5 TE
P28	stainless steel + UCF Coating		137	272.5 TE
P29	waterproof (UCF Coating)		133	243.5 TE
P20	woven		----	----- TE

Note: TH = tore with force; TE = tore easily; F or Flame = flame through weave; Burn = burned/melted; ? = shriveled badly and temperature could not be determined accurately.

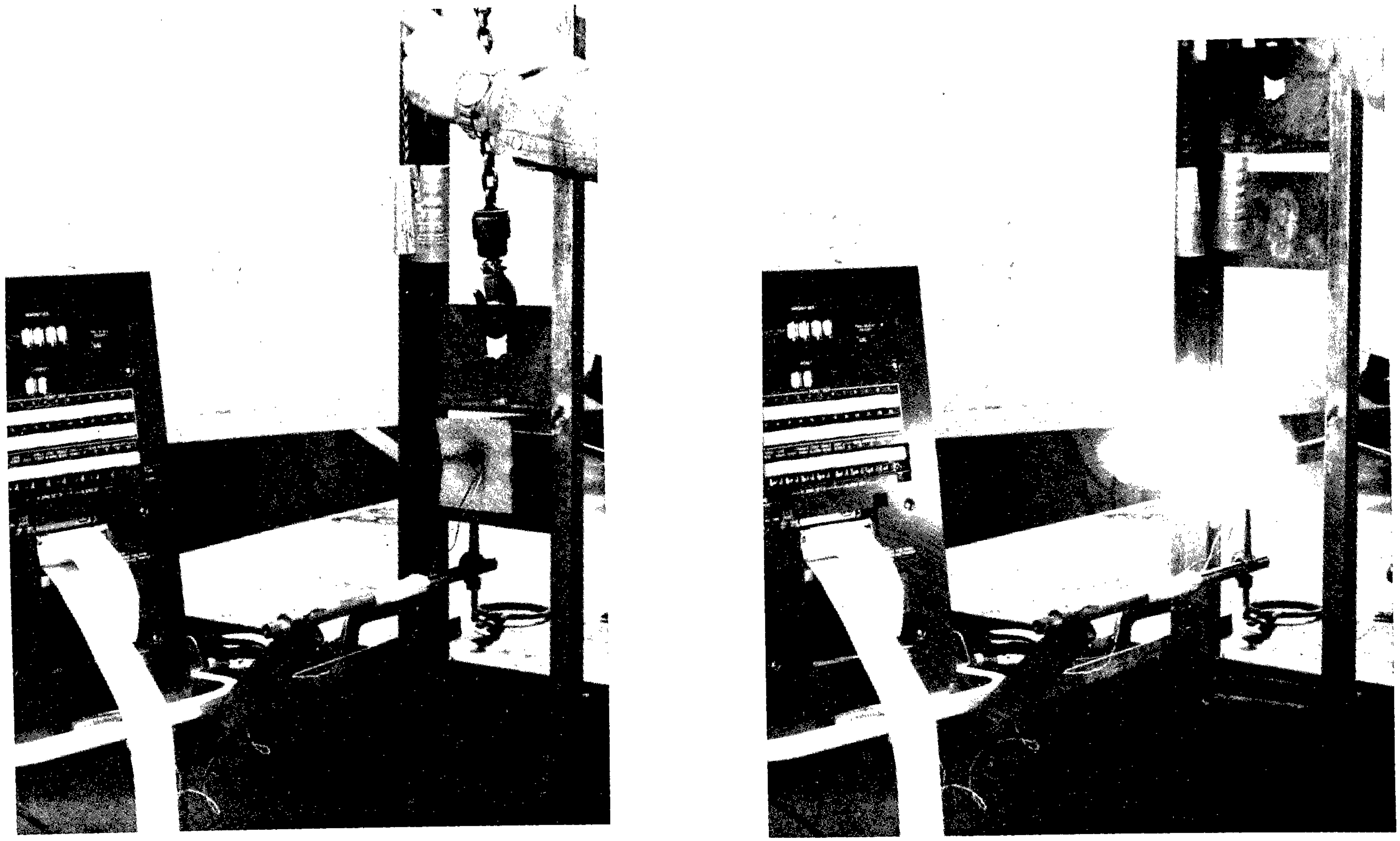

FIGURE 1. Test Apparatus (Before and During Fabric Test Trial)

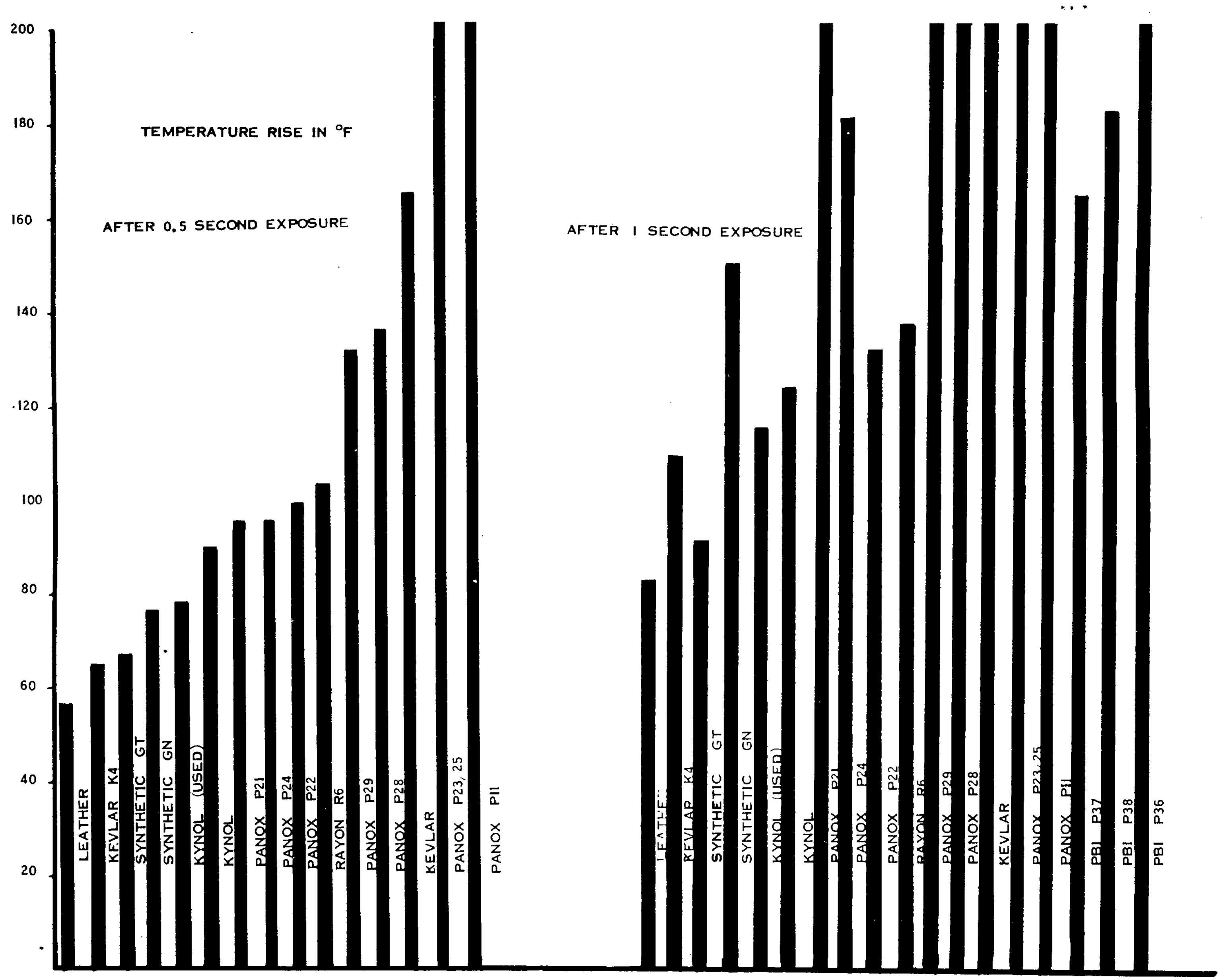

FIGURE 2. Maximum Temperature Rises

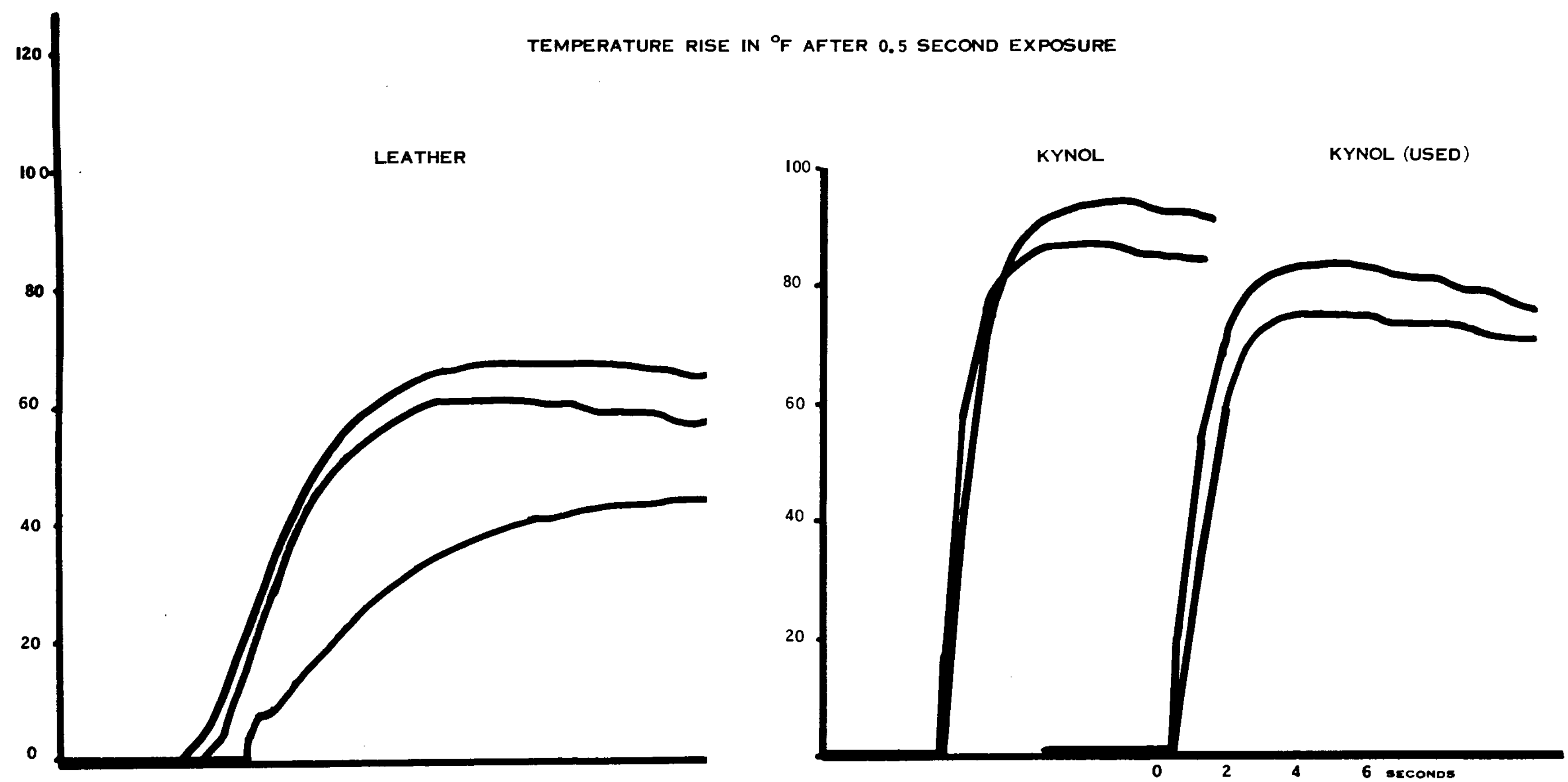

FIGURE 3. Temperature Curves for 0.5 Second Exposure for Leather and Kynol Fabrics

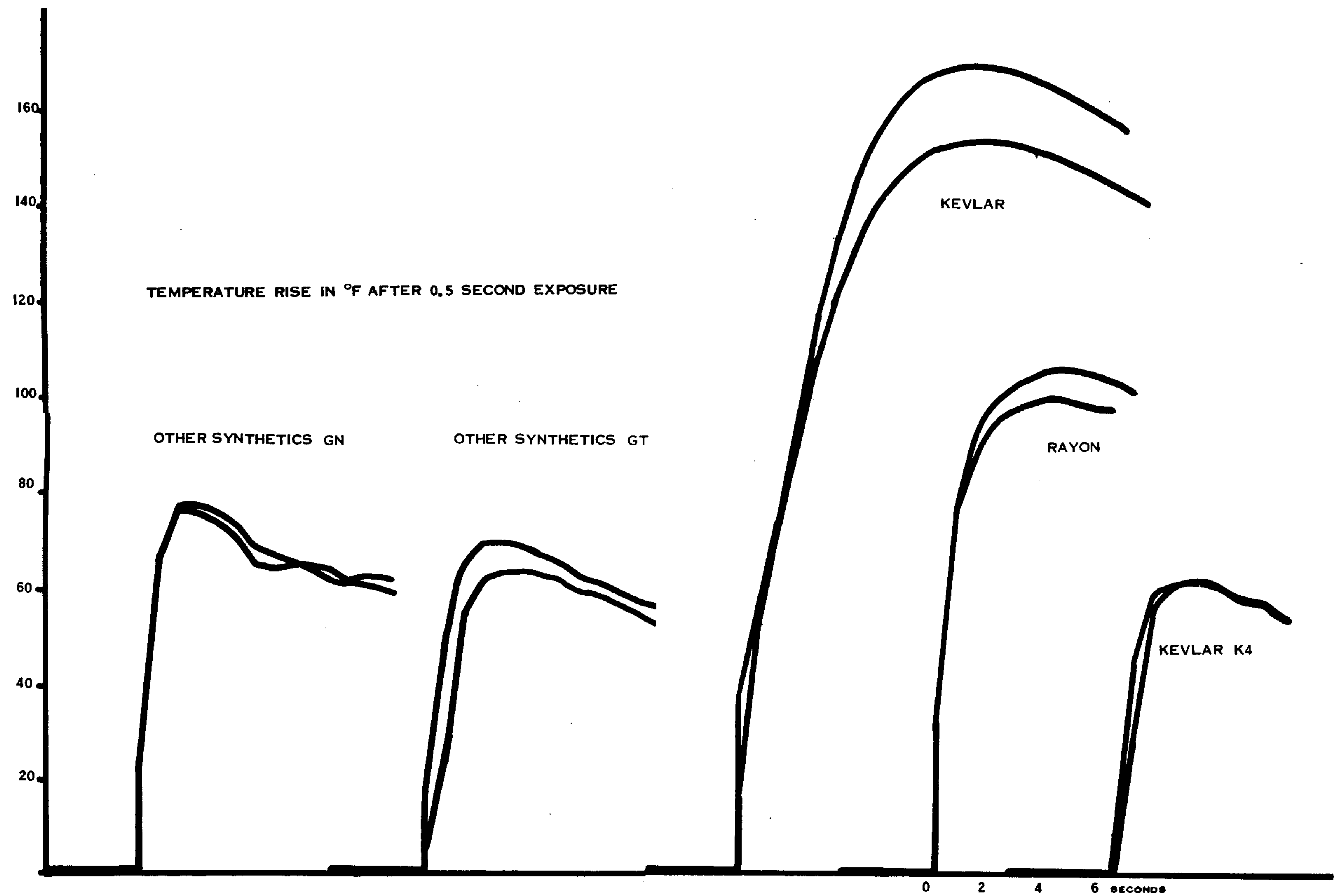

FIGURE 4. Temperature Curves for 0.5 Second Exposure for Kevlar, Rayon, and Other Synthetic Fabric

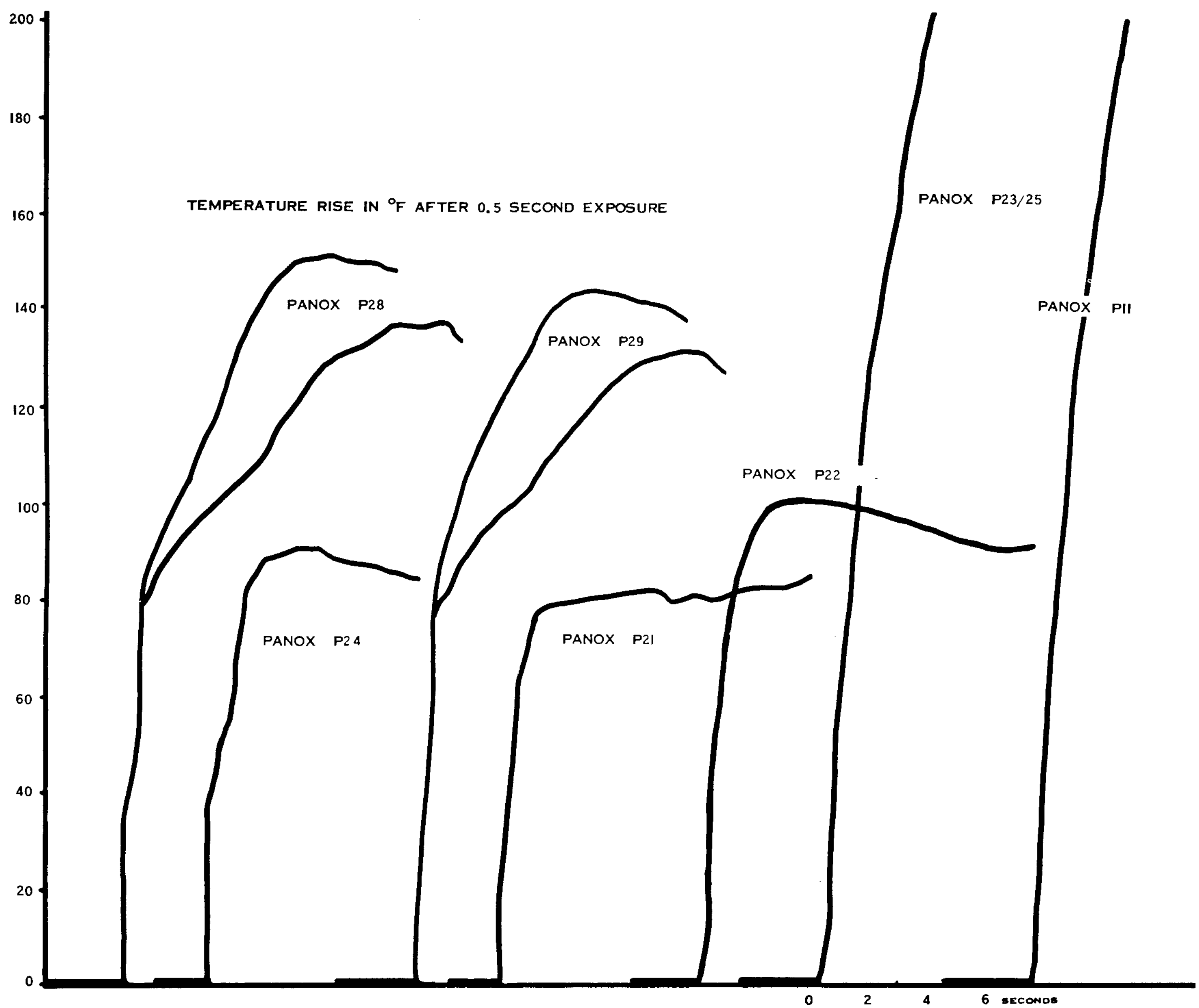

FIGURE 5. Temperature Curves for 0.5 Second Exposure for Types of Panox Fabrics

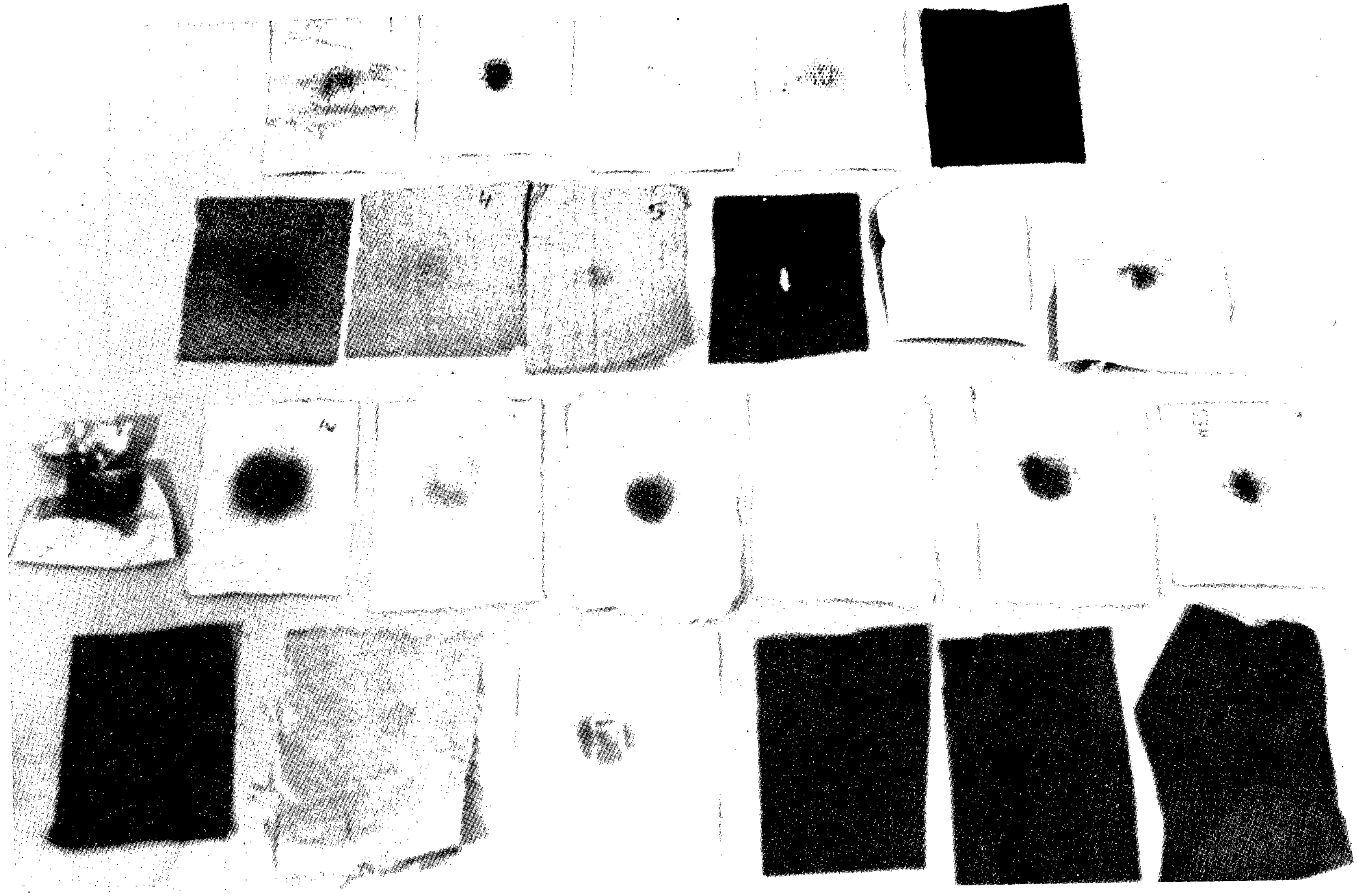

FIGURE 6. Samples of Fabrics Exposed to Oxyacetylene Flame for One Second
(Protected Side Is Shown)

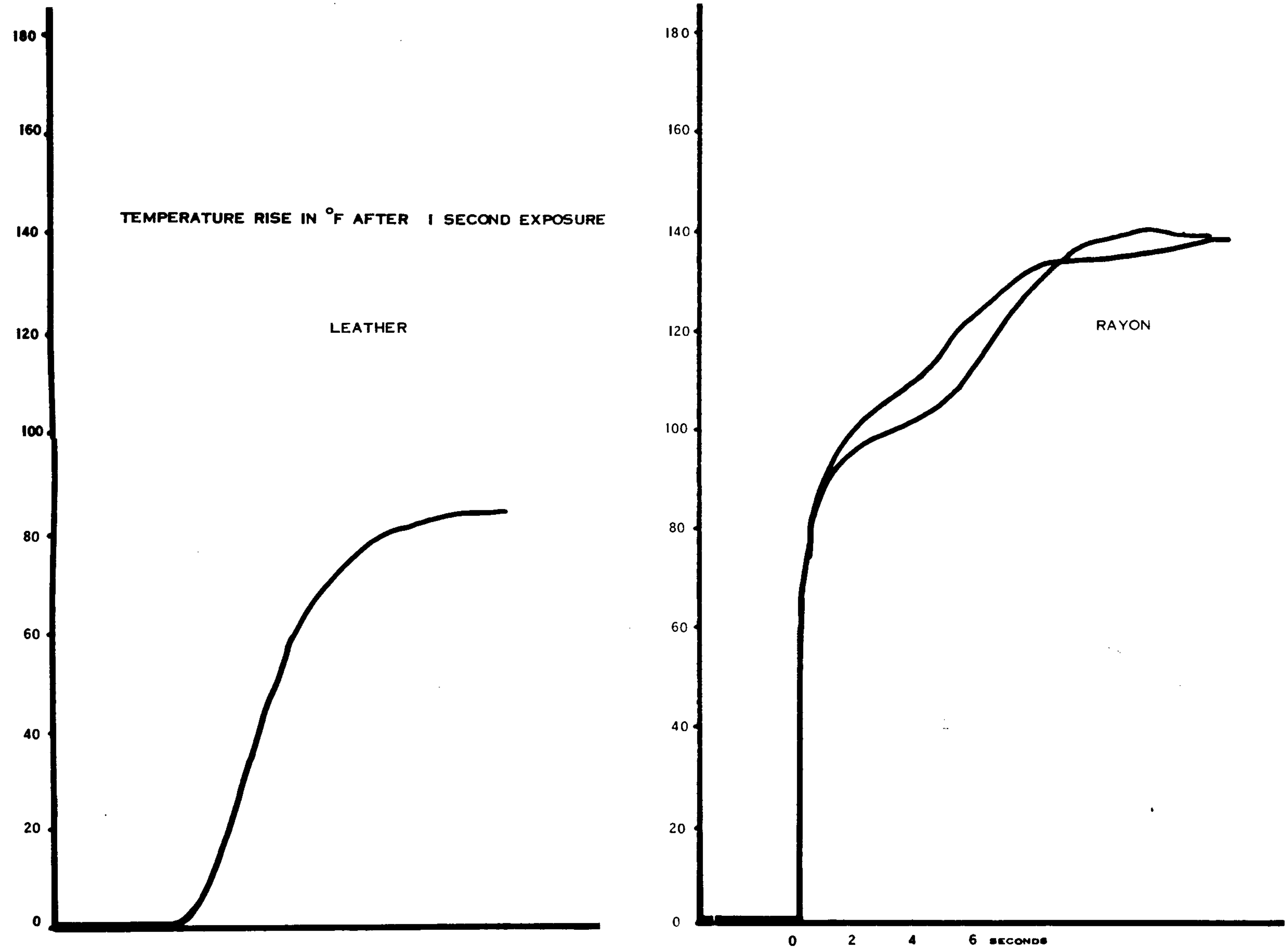

FIGURE 7. Temperature Curves for 1.0 Second Exposure for Leather and Rayon Fabric

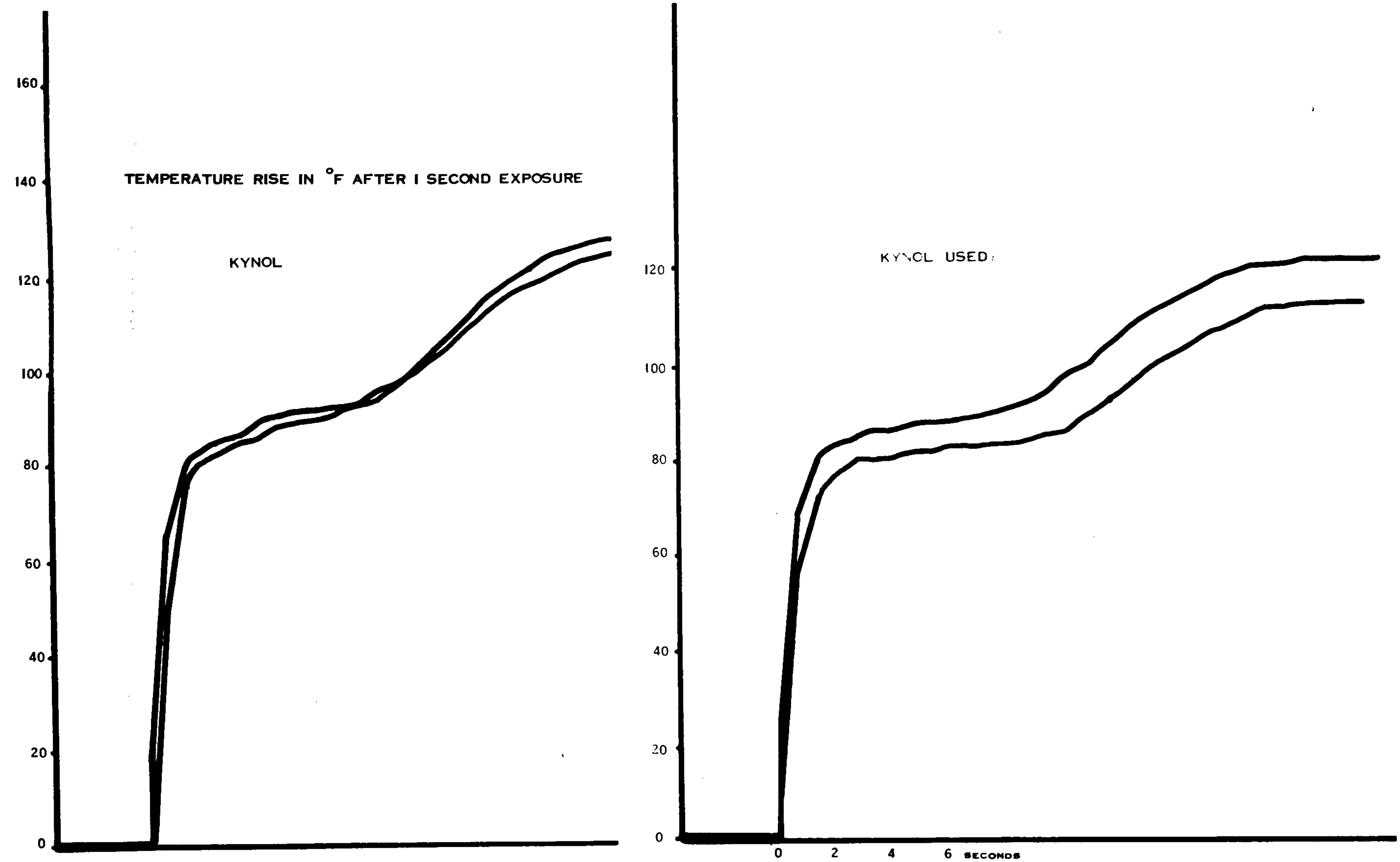

FIGURE 8. Temperature Curves for 1.0 Second Exposure for Kynol Fabrics

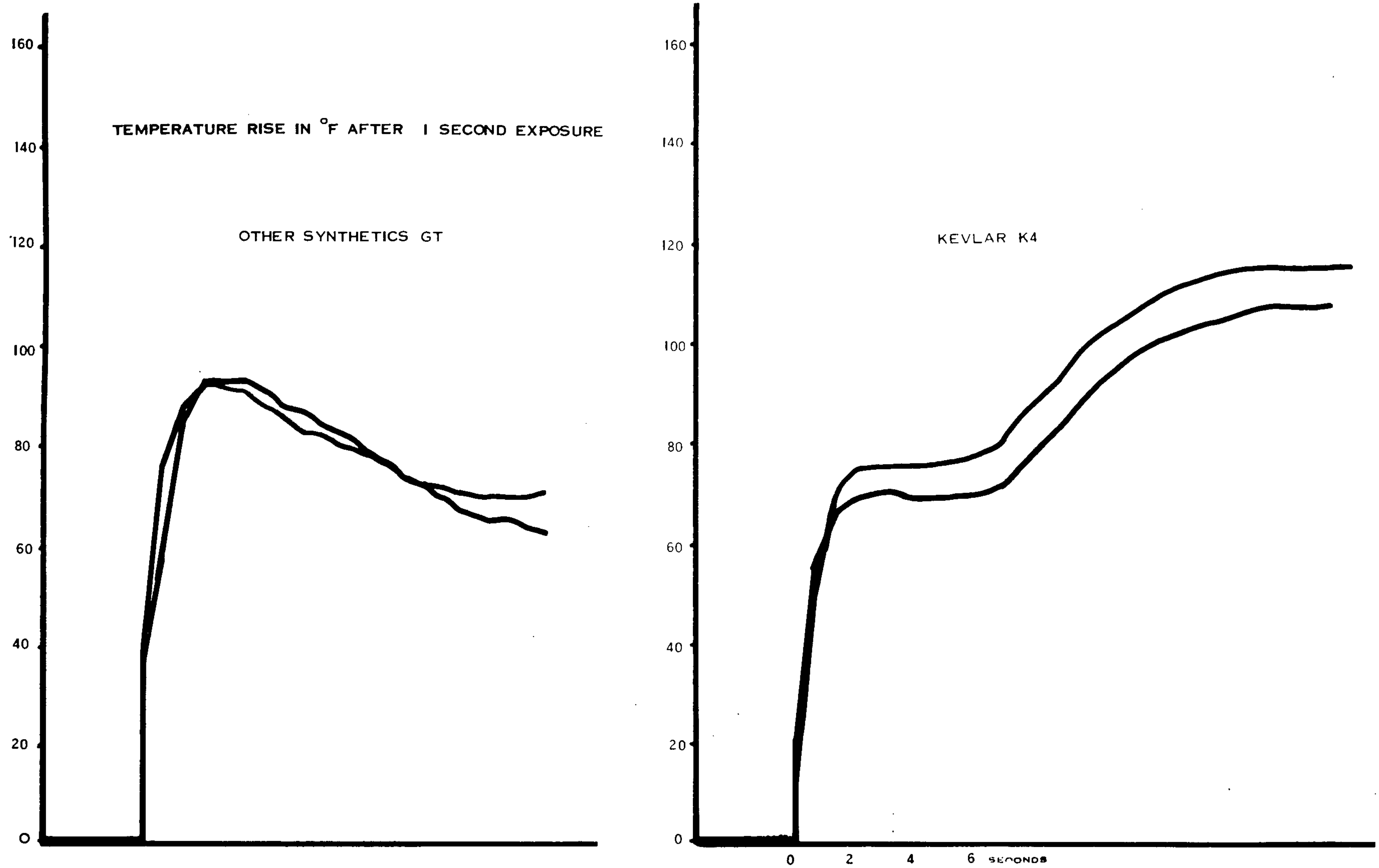

FIGURE 9. Temperature Curves for 1.0 Second for Kevlar and Other Synthetic Fabrics

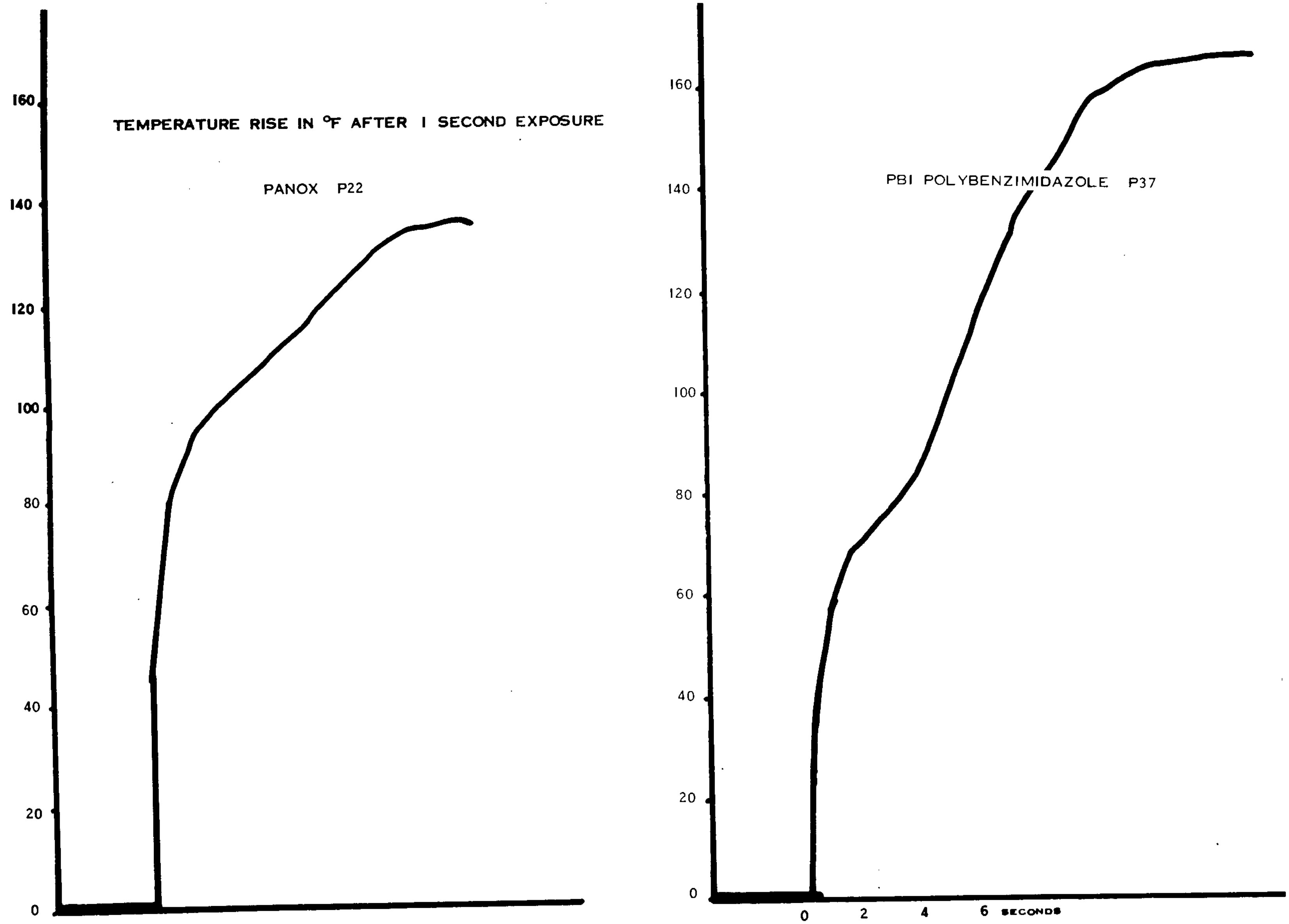

FIGURE 10. Temperature Curves for 1.0 Second for Panox and PBI Fabric

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